# Middle ear implant for sensorineural, conductive and

# mixed hearing losses

**July 2010**

MSAC application 1137

**Assessment report**

**© Commonwealth of Australia 2010**

**ISBN (Print) 978-1-74241-347-1**

**ISBN (Online) 978-1-74241-348-8**

**ISSN (Print) 1443-7120**

**ISSN (Online) 1443-7139**

**First printed November 2010**

**Paper-based publications**

(c) Commonwealth of Australia 2010

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968*, no part may be

reproduced by any process without prior written permission from the Commonwealth. Requests and inquiries concerning reproduction and rights should be addressed to the Commonwealth Copyright Administration, Attorney-General's Department, Robert Garran Offices, National Circuit, Barton ACT

2600 or posted at <http://www.ag.gov.au/cca>

**Internet sites**

(c) Commonwealth of Australia 2010

This work is copyright. You may download, display, print and reproduce this material in unaltered form

only (retaining this notice) for your personal, non-commercial use or use within your organisation. Apart from any use as permitted under the *Copyright Act 1968*, all other rights are reserved. Requests and inquiries concerning reproduction and rights should be addressed to Commonwealth Copyright Administration, Attorney-General's Department, Robert Garran Offices, National Circuit, Barton ACT 2600 or posted at<http://www.ag.gov.au/cca>

Electronic copies of the report can be obtained from the Medical Service Advisory Committee’s Internet site [at http://www.msac.gov.au/](http://www.msac.gov.au/)

Printed copies of the report can be obtained from: The Secretary

Medical Services Advisory Committee

Department of Health and Ageing

Mail Drop 853

GPO Box 9848

Canberra ACT 2601

Enquiries about the content of the report should be directed to the above address.

The Medical Services Advisory Committee (MSAC) is an independent committee which has been established to provide advice to the Minister for Health and Ageing on the strength of evidence available on new and existing medical technologies and procedures in terms of their safety, effectiveness and cost- effectiveness. This advice will help to inform government decisions about which medical services should attract funding under Medicare.

MSAC’s advice does not necessarily reflect the views of all individuals who participated in the MSAC

evaluation.

This report was prepared by the Medical Services Advisory Committee with the assistance of Mrs Caryn Perera, Dr Prema Thavaneswaran and Mr Irving Lee from Australian Safety and Efficacy Register of New Interventional Products – Surgical (ASERNIP-S) and Ms Jody Church from Centre for Health Economics Research and Evaluation (CHERE). The report was edited by ASERNIP-S.

Publication approval number: D0120

**Table of Contents**

[Middle ear implant for sensorineural, conductive and 1](#_Toc371510213)

[mixed hearing losses 1](#_Toc371510214)

[Executive summary 1](#_Toc371510215)

[Introduction 6](#_Toc371510216)

[Background 7](#_Toc371510217)

[Clinical need/burden of disease 10](#_Toc371510218)

[Existing procedures 10](#_Toc371510219)

[Comparator 16](#_Toc371510220)

[Marketing status of the device/technology 16](#_Toc371510221)

[Approach to assessment 20](#_Toc371510222)

[Review of literature 20](#_Toc371510223)

[Results of assessment 28](#_Toc371510224)

[Descriptive characteristics of included studies 28](#_Toc371510225)

[Systematic reviews 43](#_Toc371510226)

[Critical appraisal 44](#_Toc371510227)

[Is it safe? 47](#_Toc371510228)

[Is it effective? 68](#_Toc371510229)

[Other considerations 103](#_Toc371510230)

[Summary of effectiveness outcomes 104](#_Toc371510231)

[Expert opinion 107](#_Toc371510232)

[What are the economic considerations? 108](#_Toc371510233)

[Discussion 121](#_Toc371510234)

[Limitations of the evidence 121](#_Toc371510235)

[Safety 121](#_Toc371510236)

[Effectiveness 123](#_Toc371510237)

[Cost-effectiveness 123](#_Toc371510238)

[Conclusions 125](#_Toc371510239)

[Safety 125](#_Toc371510240)

[Effectiveness 125](#_Toc371510241)

[Cost-effectiveness 128](#_Toc371510242)

[Appendix A 129](#_Toc371510243)

[MSAC terms of reference and membership 129](#_Toc371510244)

[Appendix B 130](#_Toc371510245)

[Advisory panel and Evaluators 130](#_Toc371510246)

[Advisory panel for MSAC Application 1137: Middle ear implant for sensorineural, conductive and mixed hearing losses 130](#_Toc371510247)

[Economics Sub-Committee Advice to Advisory Panel 130](#_Toc371510248)

[Evaluators 130](#_Toc371510249)

[Appendix C 131](#_Toc371510250)

[Studies included in the Report 131](#_Toc371510251)

[Appendix D 138](#_Toc371510252)

[Further data tables 138](#_Toc371510253)

[Appendix E 160](#_Toc371510254)

[Excluded studies 160](#_Toc371510255)

[Abstract/conference proceeding 160](#_Toc371510256)

[Animal study 160](#_Toc371510257)

[Cadaver study 161](#_Toc371510258)

[Duplicate reporting 162](#_Toc371510259)

[English abstract only 162](#_Toc371510260)

[Insufficient length of follow-up (comparators only) 163](#_Toc371510261)

[Insufficient patients included (comparators only) 163](#_Toc371510262)

[Letter 165](#_Toc371510263)

[Middle ear implant device development 165](#_Toc371510264)

[Middle ear implant device not implanted 166](#_Toc371510265)

[No safety outcomes provided (comparators only) 167](#_Toc371510266)

[Patients had not failed external hearing aid 169](#_Toc371510267)

[Patients were not consecutively enrolled (comparators only) 169](#_Toc371510268)

[Potential duplication 172](#_Toc371510269)

[Profound hearing loss outcomes 173](#_Toc371510270)

[Review/discussion – no clinical outcomes reported 174](#_Toc371510271)

[Sudden sensorineural hearing loss 175](#_Toc371510272)

[Unavailable via inter-library loan 176](#_Toc371510273)

[Appendix F 178](#_Toc371510274)

[Clinical trials and health technology assessments 178](#_Toc371510275)

[Clinical trials 178](#_Toc371510276)

[Appendix G 179](#_Toc371510277)

[Current MBS listings for hearing loss procedures 179](#_Toc371510278)

[Appendix H 183](#_Toc371510279)

[Acronyms and abbreviations 183](#_Toc371510280)

[References 185](#_Toc371510281)

Tables

[Table 1 Guidelines for interpreting hearing loss 8](#_Toc371510750)

[Table 2 Items relating to middle ear implants listed by the TGA 16](#_Toc371510751)

[Table 3 Items relating to middle ear implants listed by the FDA 17](#_Toc371510752)

[Table 4 PICO criteria for middle ear implants for sensorineural hearing loss 20](#_Toc371510753)

[Table 5 PICO criteria for middle ear implants for mixed hearing loss 21](#_Toc371510754)

[Table 6 PICO criteria for middle ear implants for conductive hearing loss 22](#_Toc371510755)

[Table 7 Inclusion criteria for identification of relevant studies 24](#_Toc371510756)

[Table 8 Evidence dimensions 25](#_Toc371510757)

[Table 9 Designations of levels of evidence\* according to type of research question 25](#_Toc371510758)

[(including tablenotes) (NHMRC 2000) 25](#_Toc371510759)

[Table 10 Included middle ear implant studies 28](#_Toc371510760)

[Table 11 Included studies for cochlear implant 30](#_Toc371510761)

[Table 12 Included studies for bone anchored hearing aid 32](#_Toc371510762)

[Table 13 Included studies for middle ear implant for sensorineural hearing loss 33](#_Toc371510763)

[Table 14 Included studies for middle ear implant for mixed hearing loss 34](#_Toc371510764)

[Table 15 Included studies for middle ear implant for conductive hearing loss 35](#_Toc371510765)

[Table 16 Included studies for middle ear implant for undefined hearing loss 35](#_Toc371510766)

[Table 17 Comparative studies for the middle ear implant versus hearing aid in sensorineural hearing loss 37](#_Toc371510767)

[Table 18 Comparative studies for the middle ear implant versus hearing aid in mixed hearing loss 38](#_Toc371510768)

[Table 19 Comparative studies for the middle ear implant versus hearing aid in undefined hearing loss 38](#_Toc371510769)

[Table 20 FDA regulatory document for middle ear implant for sensorineural hearing loss 38](#_Toc371510770)

[Table 21 Middle ear implant devices identified in the literature search 40](#_Toc371510771)

[Table 22 Studies which reported modification of the middle ear implant 42](#_Toc371510772)

[Table 23 Mortality after MEI implantation 47](#_Toc371510773)

[Table 24 Adverse outcomes in 1222 patients receiving MEI implant 49](#_Toc371510774)

[Table 25 Description of studies in which there was a mean residual hearing loss 51](#_Toc371510775)

[Table 26 Individual patients with significant residual hearing loss after middle ear implantation 52](#_Toc371510776)

[Table 27 Air bone gap after MEI implantation in patients with MHL 53](#_Toc371510777)

[Table 28 Clinical adverse events in 9704 patients receiving a cochlear implant 56](#_Toc371510778)

[Table 29 Technical adverse events in 9704 patients receiving a cochlear implant 58](#_Toc371510779)

[Table 30 Skin reaction grades according to surgical technique 59](#_Toc371510780)

[Table 31 Adverse events in 619 patients receiving BAHA implantation 62](#_Toc371510781)

[Table 32 Mean difference between pre- and post-implantation APHAB subscales 72](#_Toc371510782)

[Table 33 Individual differences between pre- and post-implantation APHAB subscales 72](#_Toc371510783)

[Table 34 Functional gain in patients with mild or moderate SNHL 73](#_Toc371510784)

[Table 35 Case series for MEI for sensorineural hearing loss 76](#_Toc371510785)

[Table 36 SF-36 and NCIQ scores post-MEI implantation (Vibrant Soundbridge, Otologics MET) 77](#_Toc371510786)

[Table 37 Functional gain in patients with SNHL of undefined severity 78](#_Toc371510787)

[Table 38 Mean functional gain of the MEI in patients with mild or moderate mixed hearing loss 81](#_Toc371510788)

[Table 39 SRT in quiet in patients with mild or moderate mixed hearing loss 82](#_Toc371510789)

[Table 40 Speech perception at conversational level 82](#_Toc371510790)

[Table 41 Mean functional gain of the MEI in patients with mixed hearing loss 84](#_Toc371510791)

[Table 42 SRT in quiet in patients with mixed hearing loss 85](#_Toc371510792)

[Table 43 Speech perception at conversational level 85](#_Toc371510793)

[Table 44 Speech perception at conversational level 87](#_Toc371510794)

[Table 45 Mean functional gain provided by the middle ear implant versus the hearing aid in patients with sensorineural hearing loss 92](#_Toc371510795)

[Table 46 APHAB improvements of the middle ear implant compared with the hearing aid in patients with sensorineural hearing loss 93](#_Toc371510796)

[Table 47 Speech discrimination in quiet scores for the middle ear implant compared with the hearing aid in sensorineural hearing loss 95](#_Toc371510797)

[Table 48 Speech discrimination in noise scores for the middle ear implant compared with the hearing aid in sensorineural hearing loss 96](#_Toc371510798)

[Table 49 FDA regulatory data for middle ear implant for sensorineural hearing loss 98](#_Toc371510799)

[Table 50 Number of patients experiencing functional gain with the VSB compared with pre-surgery external HA 99](#_Toc371510800)

[Table 51 Individual PHAP scores for patients after VSB implantation 100](#_Toc371510801)

[Table 52 Device applicability relative to type and severity of hearing loss 110](#_Toc371510802)

[Table 53 MBS item numbers, fees and copayments 111](#_Toc371510803)

[Table 54 Calculation of average costs for MEI 114](#_Toc371510804)

[Table 55 Calculation of average costs for BAHA 114](#_Toc371510805)

[Table 56 Calculation of average costs for CI 115](#_Toc371510806)

[Table 57 Average costs per procedure 116](#_Toc371510807)

[Table 58 Average total costs for MEI, BAHA and CI 116](#_Toc371510808)

[Table 59 Incremental costs per procedure using MBS data 118](#_Toc371510809)

[Table 60 Incremental costs per procedure using MBS data (lower number of CI) 118](#_Toc371510810)

[Table 61 Incremental costs per procedure using the method proposed by the Applicant 119](#_Toc371510811)

[Table 62 Additional cost per annum for MEIs elected from an unaddressed pool that would not have been treated with either a BAHA or CI 120](#_Toc371510812)

[Table 63 Validity characteristics of comparative studies included in the report 138](#_Toc371510813)

[Table 64 Critical appraisal of case series for middle ear implant in patients with sensorineural hearing loss 142](#_Toc371510814)

[Table 65 Critical appraisal of case series for middle ear implant in patients with mixed hearing loss 143](#_Toc371510815)

[Table 66 Critical appraisal of case series for middle ear implant in conductive hearing loss 145](#_Toc371510816)

[Table 67 Patient characteristics for sensorineural hearing loss 146](#_Toc371510817)

[Table 68 Patient characteristics for mixed hearing loss 149](#_Toc371510818)

[Table 69 Patient characteristics for conductive hearing loss 151](#_Toc371510819)

[Table 70 Patient characteristics for undefined hearing loss 151](#_Toc371510820)

[Table 71 Technical characteristics for sensorineural hearing loss 152](#_Toc371510821)

[Table 72 Technical characteristics for mixed hearing loss 156](#_Toc371510822)

[Table 73 Technical characteristics for conductive hearing loss 158](#_Toc371510823)

[Table 74 Technical characteristics for undefined hearing loss 159](#_Toc371510824)

[Table 75 Surgical approaches to hearing loss 179](#_Toc371510825)

Figures

[Figure 1 The external, middle and inner ear 7](#_Toc371510968)

[Figure 2 Clinical decision tree for middle ear implant for sensorineural hearing loss 13](#_Toc371510969)

[Figure 3 Clinical decision tree for middle ear implant for mixed hearing loss 14](#_Toc371510970)

[Figure 4 Clinical decision tree for middle ear implant for conductive hearing loss 15](#_Toc371510971)

## Executive summary

**The procedure**

Middle ear implants (MEI) are surgically implanted electronic devices which aim to correct hearing loss through stimulation of the ossicular chain or middle ear (Manrique et al 2008). MEI are placed into the middle ear and generally leave the external auditory canal (EAC) open and unobstructed. The basic components of MEI are a microphone,

an audio processor, a battery, a receptor and a vibration transducer which attaches to the ossicular chain (Manrique et al 2008). The transducer may be either piezoelectric or electromagnetic and produces vibrational energy that subsequently vibrates the ossicular chain (Kulkarni and Hartley 2008).

MEI are proposed for use in patients with sensorineural, conductive or mixed hearing losses. MEI are not indicated for people with profound hearing loss. All patients eligible for MEI implantation will have failed all appropriate conservative therapies, including an optimally-fitted external hearing aid.

The clinical comparators for the MEI vary according to the type and severity of hearing loss. In patients with mild or moderate sensorineural, conductive or mixed hearing

losses, the comparator is the bone anchored hearing aid (BAHA). In patients with severe sensorineural or mixed hearing losses, the comparator is the cochlear implant (CI). In patients with severe conductive hearing loss, the comparator is the BAHA.

**Medical Services Advisory Committee – role and approach**

The Medical Services Advisory Committee (MSAC) was established by the Australian Government to strengthen the role of evidence in health-financing decisions in Australia. MSAC advises the Minister for Health and Ageing on the evidence relating to the safety, effectiveness and cost-effectiveness of new and existing medical technologies and procedures, and the circumstances under which public funding should be supported.

A rigorous assessment of evidence is thus the basis of decision making when funding is sought under Medicare. A team from the Australian Safety and Efficacy Register of New Interventional Procedures – Surgical (ASERNIP-S) was engaged to conduct a systematic review of literature on middle ear implant for sensorineural, conductive and mixed hearing losses. An advisory panel with expertise in this area then evaluated the evidence and provided advice to MSAC.

**MSAC’s assessment of middle ear implant for sensorineural, conductive and mixed hearing losses**

**Clinical need**

Hearing loss is very common with approximately 13 per cent of Australians affected by total or partial hearing loss in 2004-05 (ABS 2007). In 2003 adult-onset hearing loss was ranked as the eighth leading specific cause of burden of disease and injury, comprising

2.5 per cent of the total disability-adjusted life-years (Australian Institute of Health and

Welfare 2008).

Hearing loss may lead to many adverse outcomes in both adults and children. It can hinder interpersonal communication, which may lead to social isolation, a reduction in quality of life, and stress for family and friends (Moeller 2007). Affected adults may be unable to work productively, while affected children may have language and developmental difficulties. Further, hearing loss has a lifelong impact on educational and employment opportunities (Access Economics 2006; Chang 2005; Coates et al 2002; Moeller 2007).

In many patients the use of an external hearing aid may be unacceptable. Issues relating to external hearing aids many include sound distortion, ear canal occlusion (which is particularly relevant for patients with chronic otitis externa and media), acoustic feedback, autophony, inadequate amplification, discomfort and social stigma (Chang

2005; Manrique et al 2008; Shinners et al 2008).

**Safety**

No comparative evidence was available to inform on safety of the MEI compared with either the BAHA or CI. Case series data was used to inform on the absolute safety of each device.

For the **MEI** device safety outcomes were drawn from comparative, case series and case report data for a total of 1222 patients. There were no deaths associated with MEI implantation. Most adverse events were relatively rare and of low severity. Serious adverse events such as facial nerve damage were reported to have occurred rarely. Damage to the chorda tympani nerve was reported more commonly; however, some instances of resulting taste disturbance were reported to have been transient and to have resolved over time. Technical complications related to the device, including device

malfunction, migration or insufficient gain were relatively rare. Residual hearing loss after

MEI implantation was reported on by most studies, with 13 studies reporting that patients suffered significant declines in mean residual hearing loss after MEI implantation. Communication with the manufacturer of the Vibrant Soundbridge (VSB)

device (Med-EL) indicates that this MEI is not magnetic resonance imaging (MRI) safe at any Tesla level, and the device can be removed if necessary.

Twenty case series with a total of 9704 patients were used to inform of the absolute safety of **CI**. Several intracranial adverse events which were reported in CI patients were absent in MEI patients. Meningitis was reported in 44 CI patients, two of whom died. Most of the patients with meningitis were children. Two patients were reported to have received dural damage. Cerebrospinal fluid leak was also reported exclusively in CI

patients. The incidence of tympanic membrane perforation was higher in MEI patients, most likely due to the techniques used for MEI implantation. Haematomas and extrusions also occurred more frequently in MEI than in CI. Rates of damage to the chorda tympani and the facial nerves were similar between the CI and MEI patients. Additionally, the CI and MEI devices appeared to be similar in terms of failure rates.

Seven case series with a total of 619 patients were used to inform on the absolute safety

of the **BAHA**. The BAHA appeared to be more technologically consistent than the MEI. Additionally, insufficient gain was more prevalent in MEI studies than in BAHA studies. Once positioned, the MEI appeared to be more stable than the BAHA. The BAHA also appeared to be more susceptible than the MEI to damage or loss due to trauma. Generally, BAHA patients reported more wound healing difficulty than MEI patients. This is likely to be due to the skin grafts employed in BAHA implantation, as well as the additional maintenance care required for the BAHA’s abutment area.

Expert clinical opinion endorsed by the Advisory Panel suggests that some safety issues may be more specific to children. Paediatric bone is softer than that of adults and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage. Additionally, children may be less likely to perform BAHA site maintenance and hygiene. In patients reported to have received the MEI, only one adverse event, a haematoma, was reported to have occurred in a child. No association was made between the age of this patient and the complication.

Residual hearing loss (RHL) after implantation was an important adverse event which was only reported in MEI patients. RHL was reported upon by most MEI studies, with

13 studies reporting that patients suffered significant declines in mean residual hearing after MEI implantation. Unlike the CI literature, the MEI literature included many patients with mild or moderate HL. In these patients, any further deterioration in hearing may be of greater clinical importance compared with losses in patients with severe or profound HL. Patients with conductive hearing loss (CHL) did not report significantly worse residual hearing after implantation.

Adverse events were reported inconsistently across the MEI, CI and BAHA studies, with no standardised definitions utilised. The types of adverse events also differed between these devices. As a result, the incidence of some adverse events is highly variable

between studies.

The substantial difference in patient numbers available to assess the safety of the MEI, CI and BAHA reflects the relative youth of the MEI procedure. This is particularly the case for CI and reflects the more established nature of CI as a treatment for HL.

In summary, due to the absence of comparative evidence it is not possible to accurately compare the rates of adverse events between patients receiving MEI, CI or BAHA. However, on the limited evidence that is available, it appears that MEI implantation is at least as safe as CI or BAHA implantation.

**Effectiveness**

There was a paucity of high level evidence with which to assess the effectiveness of the MEI. One comparative study (National Health and Medical Research Council (NHMRC) level III-3) was available to assess the effectiveness of the MEI versus the CI, while no comparative studies were available to assess the effectiveness of the MEI versus the BAHA. Three comparative studies of the MEI device alone were identified; however, these studies generally involved an internal comparator such as MEI attachment method. Hence, most of the evidence for the effectiveness of the MEI has been derived from level IV evidence. Some studies assessed outcomes after MEI implantation, while others assessed outcomes with the MEI switched off and then on.

Eighteen comparative studies were available to assess the effectiveness of the MEI versus the external hearing aid (HA), and these were supplemented by a Food and Drug Administration (FDA) regulatory document.

Generally, MEI implantation and/or activation led to improvements in patients with mild, moderate and severe sensorineural hearing loss (SNHL); SNHL of undefined severity; mild, moderate and severe mixed hearing loss (MHL); MHL of undefined severity; and CHL. The MEI appears to be at least as effective as the HA. However, these conclusions are limited by the paucity of high-level evidence. Many effectiveness outcomes were reported in case series, and subject to bias. The lack of high quality studies may be related to the relative youth of the MEI procedure.

The included studies displayed considerable variability regarding patient enrolment, study design and length of follow-up. Several studies assessed the MEI in patients who had a range of hearing severities, such as mild to severe, which made meaningful reporting of these various severities difficult.

The included studies presented a variety of MEI devices. While most studies assessed the VSB MEI, the Otologics middle ear transducer (MET), Envoy Esteem, Rion device, SOUNDTEC Direct Drive Hearing System (DDHS) and TICA MEIs were also assessed. Additionally, some studies described instances in which the MEI attachment method or the devices themselves had been modified to permit implantation. Hence, differences in components and attachment occurred between the six identified MEI devices and also between patients receiving the same MEI. Expert opinion of the Advisory Panel stated that although there were slight differences between the MEI devices, their method of implantation was similar enough for pooled outcomes to be reported.

The majority of the available studies assessed the MEI in patients with SNHL. This is reflective of the anticipated Australian practice suggested by clinical experts.

The reporting of effectiveness outcomes was compromised by the lack of uniform outcome measurements. While the primary technical outcome measure (functional gain) was identified a priori, not all studies reported this outcome. Patient-related outcomes were not reported in all studies. Where these were reported, different outcome measures such as the Glasgow Benefits Index (GBI) and the SF-36 were used.

Effectiveness outcomes were further compromised by the fact that some studies reported that baseline measurements were taken with a digital, best fit, or state-of-the-art HA, while others used the patient’s own HA. Further, in some before/after MEI studies it was not clearly stated whether baseline measures were measured with or without a HA. It appears

that presently there is considerable variability in HA management prior to the consideration of MEI implantation.

**Cost-effectiveness**

The objective of the economic evaluation was to compare the cost-effectiveness of MEI relative to BAHA and CI. In the absence of conclusive effectiveness data, a cost analysis was conducted to compare the different costs associated with each of the three procedures.

The estimated costs of MEI, BAHA and CI were taken from a number of sources. These included the Medicare Benefits Schedule (MBS), Australian Refined Diagnostic Related Group (AR-DRG) cost, manufacturers of implants and the median charged MBS fee.

Based on a number of estimates and assumptions:

 The total estimated first year cost of an MEI, BAHA and CI is $23,873, $15,207 and

$34,466, respectively. The incremental cost of using an MEI as opposed to a BAHA

is $8,666. The incremental cost saving of using an MEI as opposed to a CI is

$10,593.

 Based on 2006-07 MBS data, the total cost of BAHA would be $1,611,957 (106 patients) and the total cost of CI would be $11,270,250 (327 patients). This gives a total cost of $12,882,207. If MEI was used instead of BAHA and CI the total cost would be $10,336,916. Hence the cost savings of performing MEI as a direct replacement for BAHA and CI would be over $2.5 million.

 Expert opinion endorsed by the Advisory Panel indicated that MEI would not just replace current CI and BAHA use, but would become another option in meeting the pool of unmet need of those with hearing loss. Expert opinion was that these individuals, currently persisting with hearing loss or a less than optimal hearing aid, may consider MEI implantation while they are not considering or accessing BAHA or CI. The previously mentioned variability in HA management prior to consideration of MEI, and limited data on the pool of ‘unmet need’, makes this number difficult to quantify. Sensitivity analysis suggests that if one per cent of the estimated pool of individuals with moderate or severe hearing loss elected to have MEI, the additional cost would be $2,291,787. These estimates are based on prevalence data of hearing loss in Australia and include a large portion of older Australians for whom an MEI would not be viable.

## Introduction

The Medical Services Advisory Committee (MSAC) has reviewed the use of middle ear implant, which is a therapy for hearing loss. MSAC evaluates new and existing health technologies and procedures for which funding is sought under the Medicare Benefits Schedule (MBS) in terms of their safety, effectiveness and cost-effectiveness, while taking into account other issues such as access and equity. MSAC adopts an evidence-based approach to its assessments, based on reviews of the scientific literature and other information sources, including clinical expertise.

MSAC’s terms of reference and membership are at Appendix A. MSAC is a multidisciplinary expert body, comprising members drawn from such disciplines as diagnostic imaging, pathology, surgery, internal medicine and general practice, clinical epidemiology, health economics, consumer health and health administration.

This report summarises the assessment of current evidence for middle ear implant for sensorineural, conductive and mixed hearing losses.

## Background

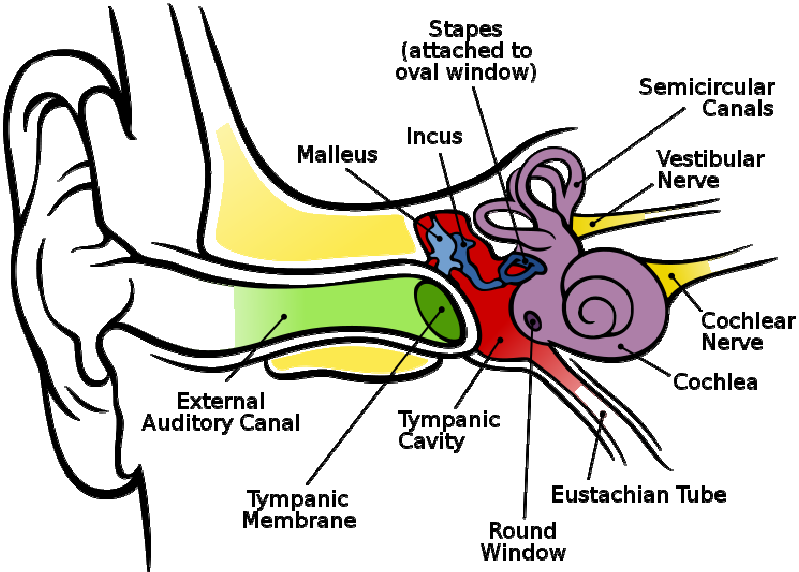
**Hearing and hearing loss**

The function of the ear is to transduce acoustic energy into electrical energy which may be perceived by the brain as sound. The ear comprises three zones: the outer, middle and inner ear. The outer ear consists of the pinna and the external auditory canal (EAC). Sound is funnelled by the pinna along the EAC to the middle ear. The middle ear comprises the tympanic membrane (eardrum) and a series of three tiny interlocking

bones (malleus, incus and stapes) known collectively as the ossicular chain (Weissman

1996), which span an air-filled space called the tympanic cavity. Sound waves cause the tympanic membrane to vibrate, which in turn moves the ossicular chain and amplifies the sound. The air pressure on either side of the tympanic membrane is equalised by the Eustachian tube (Counter 2008), which connects the tympanic cavity to the throat.

##### Figure 1 The external, middle and inner ear



Source: Perception Space—The Final Frontier, A PLoS Biology Vol. 3, No. 4, e137 doi:10.1371/journal.pbio.0030137

The inner ear is a bony labyrinth containing the fluid-filled cochlea that is responsible for hearing and the vestibular apparatus, which is the organ of balance. The foot of the

stapes is connected to the oval window, a flexible membrane of the cochlea (Wilson and Dorman 2008). When the stapes presses into the oval window a disturbance or movement is created in the cochlear fluid; a second window (the round window) flexes to permit such movement. The fluid movement causes sensitive hair cells within the cochlea to bend, generating electrical signals that are sent to the brain via the auditory nerve. Thus, the cochlea transduces the vibrations caused by the stapes into electrical

signals. Sound waves may be conducted to the cochlea through air via the middle ear (air conduction) or via the mastoid when the sound source is in contact with the head (bone conduction) (Lalwani 2008; Tjellstrom et al 2001).

The human ear is able to process sound frequencies ranging from 20 Hz to 20 kHz (Yueh et al 2003). Hearing loss is measured in an audiogram which uses the decibels hearing level (dB HL) as the units of measurement. For people with normal hearing the minimal audible level (threshold) of a tone is less than 20 dB across all frequencies. People with higher thresholds are considered to have hearing loss, which may be classified into mild, moderate, severe and profound hearing loss (Table 1) (Kulkarni and Hartley 2008).

#### Table 1 Guidelines for interpreting hearing loss

| **Hearing threshold (dB)** | **Interpretation** |
| --- | --- |
| 20-39 | Mild hearing loss |
| 40-69 | Moderate hearing loss |
| 70-94 | Severe hearing loss |
| 95+ | Profound hearing loss |

Source: Newton 2009

Hearing loss may be broadly grouped into three categories: sensorineural, conductive and mixed. Sensorineural hearing loss (SNHL) occurs where there is damage to either the

hair cells of the cochlea (sensory) or to the nerve pathway from the inner ear to the brain (neural) (American Speech-Language-Hearing Association 2009). SNHL may be congenital or acquired and is usually permanent (Access Economics 2006). SNHL can be caused by damage or malformation of the cochlea and the sensitive hairs, exposure to excessive noise, vestibular schwannomas, viral infections, temporal bone fractures, Meniere’s disease, ototoxic medications and the ageing process (presbycusis hearing loss) (Access Economics 2006; Lalwani 2008). Additionally, patients with idiopathic SNHL may have experienced a viral infection of the inner ear or a vascular accident (Lalwani

2008). As there is currently no method for repairing damaged cochlear hairs, treatment for SNHL usually involves amplifying the incoming sound (Yuen et al 2003).

Conductive hearing loss (CHL) occurs when sound is not conducted efficiently through the EAC to the tympanic membrane and ossicular chain (American Speech-Language- Hearing Association 2009). This is generally caused by a blockage or damage in the outer or middle ear (or both) and may be transient or permanent (Access Economics 2006; Australian Hearing 2008). Potential causes of CHL include outer ear infection; malformation of the outer or middle ear; blockages of the EAC by cerumen or foreign objects; blockage of the Eustachian tube (e.g. otitis media); perforation of the tympanic membrane; and damage of the tympanic membrane, EAC or ossicular chain. Many

causes of CHL are mechanical in nature; hence, the treatment is often surgical (Yueh et al

2003).

Mixed hearing loss (MHL) occurs when there are interruptions in both the conductive and the sensorineural pathways. Patients may have damaged outer or middle ears as well as an impaired cochlea or auditory nerve (American Speech-Language-Hearing Association 2009; Australian Hearing 2008).

Pure-tone air conduction testing is used to measure the function of a person’s entire hearing system (external, middle and inner ear). The testing is done by presenting pure tones ranging from 250 to 8000 Hz to the person. When plotted on an audiogram, the person’s pure-tone thresholds indicate the severity of their hearing loss. Pure-tone

average (PTA) thresholds between 0-20 dB are considered normal, whereas thresholds greater than 20 dB represent various levels of hearing loss (Table 1).

Bone conduction testing is used to measure the function of a person’s inner ear, as it is unaffected by damage to the outer or middle ear. The testing is generally conducted by touching the base of a vibrating tuning fork to the person’s forehead (Counter 2008). Any differences between air-conduction (AC) and bone-conduction (BC) thresholds allow classification of the person’s type of hearing loss. When the AC thresholds are higher than normal BC thresholds (i.e. an air bone gap is present), the loss is classified as CHL. When AC and BC thresholds are equivalent, the loss is classified as SNHL. When AC thresholds are higher than abnormal BC thresholds, the loss is classified as MHL (Cummings 2005).

**The procedure**

Middle ear implants (MEI) are surgically implanted electronic devices which aim to correct hearing loss through stimulation of the ossicular chain or middle ear (Manrique et al 2008). MEI are placed into the middle ear and generally leave the EAC open and unobstructed. The basic components of MEI are a microphone, an audio processor, a battery, a receptor and a vibration transducer which attaches to the ossicular chain (Manrique et al 2008). The transducer may be either piezoelectric or electromagnetic and produces vibrational energy that subsequently vibrates the ossicular chain (Kulkarni and Hartley 2008). Secure attachment of the transducer to the ossicular chain is important as separation will result in device failure (Shinners et al 2008). Among the many attachment options are: creating an opening in the incus and using an adhesive; crimping the device

to the incus; or disarticulation and placement of the device at the incudostapedial joint

(Shinners et al 2008).

MEI may remove many issues relating to hearing aid use such as sound distortion, ear canal occlusion (particularly relevant for patients with chronic otitis externa and media), acoustic feedback, autophony, inadequate amplification, discomfort and social stigma (Chang 2005; Manrique et al 2008; Shinners et al 2008). Some fully implantable MEI also allow patients to swim and wash while wearing the device (Backous and Duke 2006).

However, there may be hazards associated with MEI. Implantation requires surgery (usually requiring a general anaesthesia), and device failure will require a further operation. There is a risk of perioperative damage to the chorda tympani nerve, which can result in a change in the sensation of taste (dysgeusia), or can affect the facial nerve, which can lead to facial paralysis (Lloyd et al 2007). Cochlear function may actually decline due to the noise generated (drilling and sucking) during the surgical procedure

(Snik and Cremers 2000). Mass loading of the ossicular chain may lead to residual hearing loss, the extent of which is directly related to the weight of the MEI and to the location

of its placement in the middle ear (Hough et al 2001; Vincent et al 2004). Further, there is a potential risk of damage to the ossicular chain, and the use of magnetic resonance imaging, electroconvulsive therapy and radiotherapy of the head may be restricted with some devices (Manrique et al 2008).

### Clinical need/burden of disease

Hearing loss is very common with approximately 13 per cent of Australians affected by total or partial hearing loss in 2004-05 (Australian Bureau of Statistics 2007). Among South Australians aged 15 and older, 20.2 per cent have SNHL, 1.6 per cent have MHL and 0.4 per cent have CHL (Wilson et al 1998). In 2003 adult-onset hearing loss was ranked as the eighth leading specific cause of burden of disease and injury, comprising

2.5 per cent of the total disability-adjusted life-years (Australian Institute of Health and

Welfare 2008).

The most common type of SNHL is presbycusis or age-related hearing loss (Lalwani

2008; National Institute for Health and Clinical Excellence 2009). As the Australian population ages it is likely that the number of people suffering from hearing loss will increase (Australian Institute of Health and Welfare 2008).

Otitis media is a very common childhood infection (Rovers 2008). Between 2004 and

2005, two per cent of children receiving medical treatment were non-indigenous children with otitis media, compared with four per cent for indigenous children (Australian Institute of Health and Welfare 2007).

Hearing loss may lead to many adverse outcomes in both adults and children. It can hinder interpersonal communication, which may lead to social isolation, a reduction in quality of life, and stress for family and friends (Moeller 2007). Affected adults may be unable to work productively, while affected children may have language and developmental difficulties. Further, hearing loss has a lifelong impact on educational and employment opportunities (Access Economics 2006; Chang 2005; Coates et al 2002; Moeller 2007).

### Existing procedures

**Conservative treatments**

There are many pharmacologic and medical therapies for managing SNHL, CHL and MHL. Depending on the type of hearing loss, current conservative clinical management includes intra-tympanic inner ear steroid perfusion, antibiotics, hyperbaric oxygen or carbon gas; or external hearing aid or listening device use (Bennett et al 2006).

During 2006-07 the fitting of 124,657 hearing aids was subsidised by the Office of Hearing Services (Australian Institute of Health and Welfare 2008). While hearing aids may provide adequate amplification for many patients with hearing loss, there are some common problems with the devices which may lead to discontinuation of their use. These include control of acoustic feedback, discomfort, ear occlusion, inadequate amplification, regular maintenance tasks, hygiene of the ear canal and perceived social stigma (Backous and Duke 2006; Chang 2005; Counter 2008). Further, patients may be concerned about a hearing aid’s ease of use, reliability and frequency of battery changes. People with high-frequency hearing loss may find that a hearing aid does not perform well when there is background noise (Counter 2008). Additionally, occlusion of the ear canal may exacerbate conditions such as otitis media or otitis externa. Some patients may be unable to use conventional hearing aids due to absence or malformation of the external ear (Chang 2005).

Recently digital technology has led to advancements in hearing aid technology. Digital hearing aids are now able to provide more sophisticated sound processing through improved amplification control, situation-specific sound processing, noise reduction and improved sound localisation (O’Leary and Chang 2008). New, more sophisticated devices which aim to address specific issues such as the occlusion effect have also been

developed. These ‛open-fit’ hearing aids consist of a very small component that is placed in the ear canal, leaving it unobstructed (Harvard Health Letter 2007).

**Surgical treatments**

Surgical treatments may be explored for hearing losses which are refractory to conservative medical treatment. Table 75 shows the comprehensive range of surgical interventions related to hearing loss, with the choice of surgical procedure dependent upon the cause of hearing loss.

Surgical procedures for CHL include the following:

 Ossiculoplasty (repair or reconstruction of the middle ear)

This procedure may restore middle ear function damage due to trauma, neoplasms, inflammatory processes or cholesteatomas (Javia and Ruckenstein 2006) and can include:

- total ossicular replacement prosthesis (TORP)

- partial ossicular replacement prosthesis (PORP)

- tympanoplasty (repair of the tympanic membrane)

- stapedectomy or stapedotomy (replacement of part, or all, of the stapes, generally

performed in patients with otosclerosis or congenital malformation).

Ossiculoplasty may be performed using general or local anaesthetic (Yung 1996) and currently has several MBS item numbers (see Table 75).

 Myringotomy or insertion of tympanostomy tubes

These procedures drain fluid from the middle ear in patients with severe ear infection or otitis media with effusion. The procedures are generally performed under general anaesthetic (Koopman et al 2004). Currently, myringotomy and insertion of tympanostomy tubes each have an MBS item number (see Table 75).

 Mastoidectomy

This is indicated for patients with cholesteatomas or tumours which extend into the mastoid bone (Bennett et al 2006). Mastiodectomy currently has several MBS item numbers (see Table 75).

The following surgical procedures aim to correct hearing loss:

 Transcutaneous air conduction hearing aid system

This system comprises an implanted titanium tube and an external digital hearing aid

(Chang 2005). The titanium tube is surgically implanted through the soft tissue of the external ear into the external ear canal. The implantation procedure takes approximately 30 minutes and is usually performed under local anaesthetic (Chang

2005). The post-auricular external hearing aid connects to the titanium tube and selectively amplifies high-frequency sounds, which are then sent through the tube. The system is suitable for patients with high-tone SNHL (Chang 2005; Murugasu

2005; Winter and Lenarz 2005). Transcutaneous air conduction hearing aid systems currently have an MBS item number (see Table 75); however, expert clinical opinion suggests that this procedure has not been performed widely in Australia.

 Cochlear implant

The cochlear implant bypasses missing or damaged cochlear hair cells and directly stimulates the auditory nerve to provide auditory sensation (Chang 2005; Wilson and Dorman 2008). The implantation procedure takes approximately two hours and is performed under a general anaesthetic (Chang 2005). The cochlear implant consists of an external and an implanted component. The external component contains a microphone that detects sound and transforms it from an acoustic signal to an electromagnetic signal. This signal is then sent to the implanted component via communicating magnetic coils. The implanted component (consisting of a receiver and stimulator) is placed within the cranium, behind the auricle, and generates stimulation. A cable delivers this stimulation to the electrodes placed in the scala tympani chamber of the cochlea, which then stimulate the auditory nerve (Wilson and Dorman 2008). Cochlear implants presently have an MBS item number (see Table 75). During 2006-07, 682 public and 390 private cochlear implantations were performed (Australian Institute of Health and Welfare 2009; Medicare Australia

2009).

 Bone anchored hearing aid (BAHA)

A BAHA has a titanium plate which is implanted and anchored to the patient’s skull. The implantation procedure generally takes less than 45 minutes using local anaesthesia (Wade 2002). An external hearing aid attaches to the implanted plate.

The hearing aid detects sound waves and transforms them into vibratory signals which are transmitted to the underlying plate and bone, so that bone conduction hearing can then take place. As the BAHA bypasses both the external and the middle ear it can be used in patients with CHL (Chang 2005). Patients with SNHL

or MHL may also be candidates for a BAHA if their bone conduction thresholds do not exceed 45 dB (Chasin 2002). BAHA currently has an MBS item number (see Table 75). During 2006-07, 40 BAHA implantations were performed in the private hospital system in Australia, which rose to 123 during 2007-08 (Medicare Australia

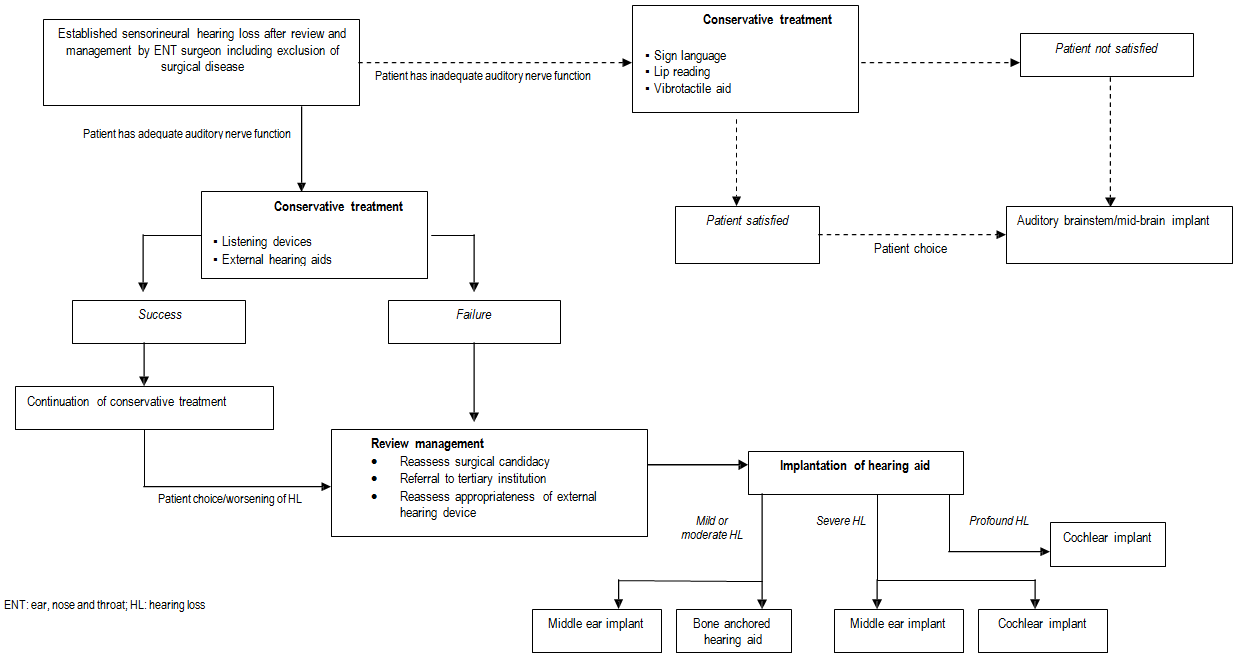
2009). Data for the public health system are unavailable.

 Auditory brainstem implant (ABI) or auditory mid-brain implant (AMI)

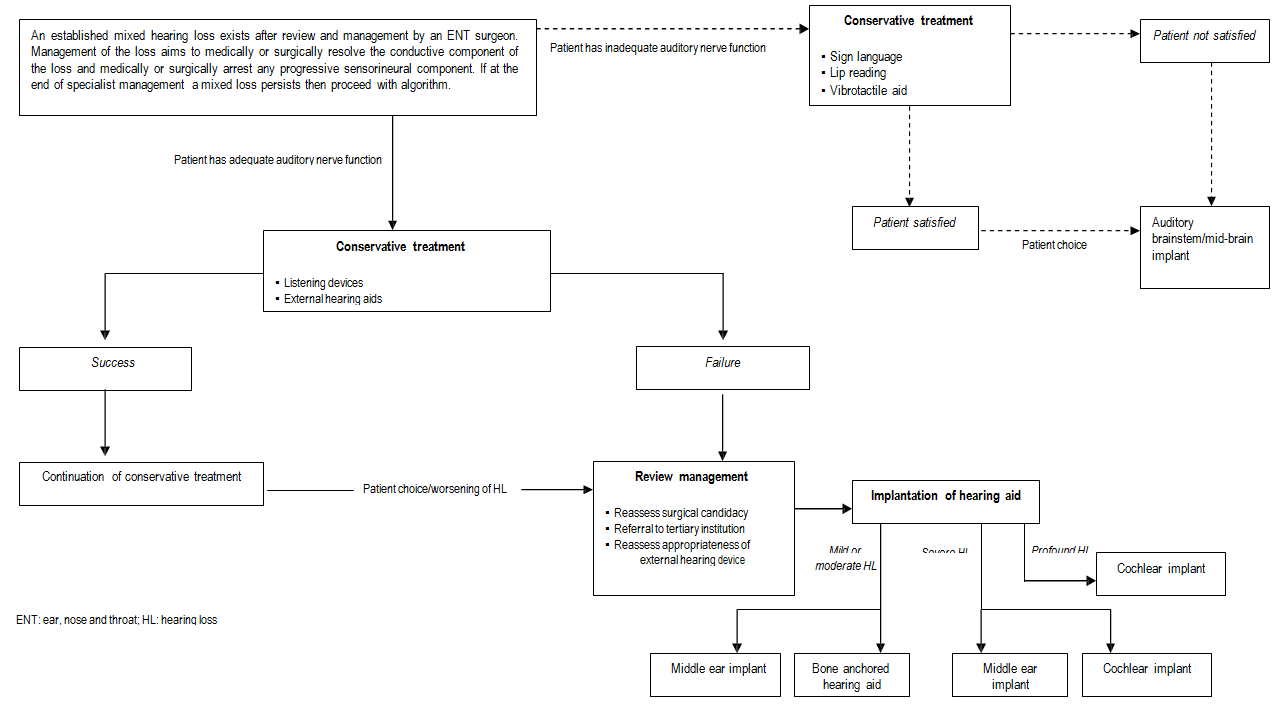
These procedures are designed for patients with insufficient auditory nerve function (Kulkarni and Hartley 2008). They are intended primarily for patients with neurofibromatosis type 2 (NF2), but may also prove useful for other conditions such as cochlear nerve aplasia (Kulkarni and Hartley 2008; Murugasu 2005). ABI and

AMI are similar to cochlear implants, although the electrodes are implanted either on the surface of the brainstem (ABI) or the mid-brain nuclei (AMI) (Kulkarni and Hartley 2008). The time taken to implant the ABI depends upon auditory brainstem response testing performed intraoperatively (Murugasu 2005). ABI and AMI do not presently have MBS item numbers.

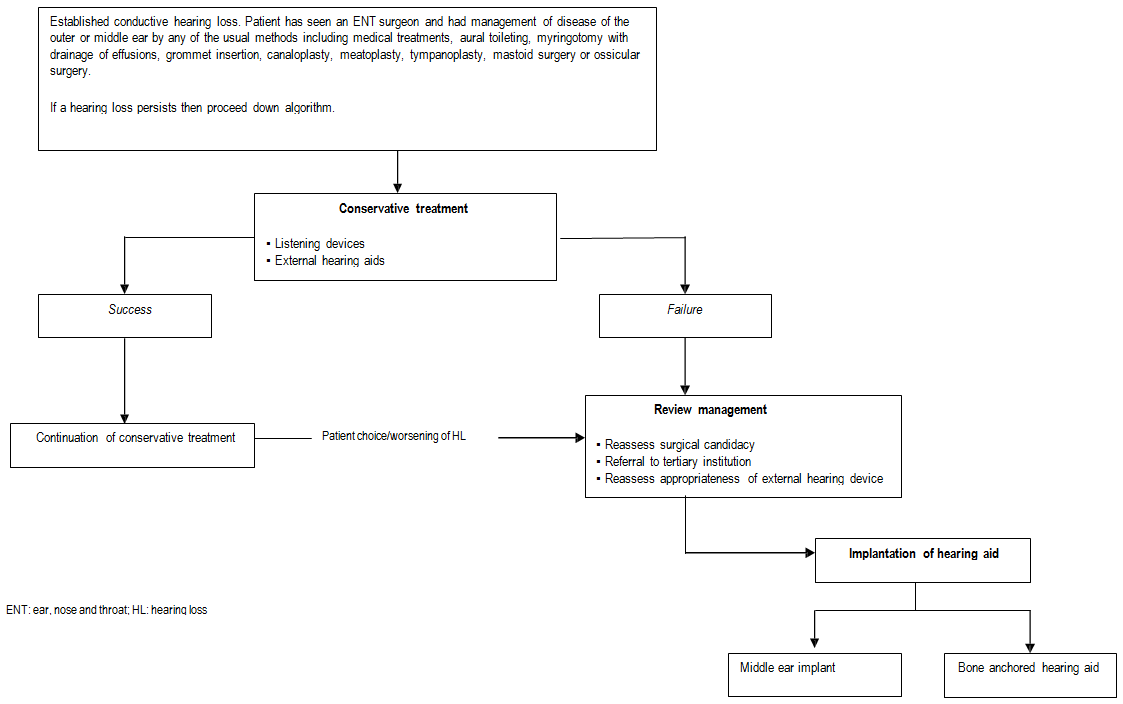
##### Figure 2 Clinical decision tree for middle ear implant for sensorineural hearing loss



##### Figure 3 Clinical decision tree for middle ear implant for mixed hearing loss



##### Figure 4 Clinical decision tree for middle ear implant for conductive hearing loss



### Comparator

The clinical comparators to the MEI are considered to be the bone-anchored hearing aid (BAHA) and the cochlear implant (CI). Expert clinical opinion advises that the BAHA is indicated in patients with mild or moderate SNHL or MHL, and in patients with stabilised CHL. The CI is indicated in patients with severe SNHL or MHL. Expert clinical opinion advises that the CI is similar to the MEI in terms of operative complexity and technique, whereas the BAHA implantation procedure is relatively simpler.

### Marketing status of the device/technology

The current Therapeutic Goods Administration (TGA) listings for middle ear implant equipment are described in Table 2. The current Food and Drug Administration (FDA) listings for middle ear implants are described in Table 3.

#### Table 2 Items relating to middle ear implants listed by the TGA

| **ARTG number** | **ARTG Label Name** | **Date**  **Approved** | **Indication** |
| --- | --- | --- | --- |
| 119161 | Progressive Medical - The Soundbridge System – Unclassified | 12/05/2005 | The Vibrant Soundbridge is indicated for use in patients who have mild to severe hearing impairment and cannot achieve success or adequate benefit from traditional therapy. This device is also indicated for conductive or mixed hearing loss using pure-tone bone- conduction. |
| 161702 | Pacing Importers Pty Ltd – Vibrant Soundbridge System Vibrating Ossicular Prosthesis (VORP) 502X – Hearing aid, middle ear implant | 12/05/2009 | The intended purpose of this device is for use in patients who have mild to severe hearing impairment and cannot achieve success or adequate benefit from traditional therapy. 1) For sensorineural HL, the VORP is crimped to the long process of the incus to directly drive the ossicular chain. 2) For mixed and conductive HL, the VORP is attached with fascia to the round window niche in the middle ear. The Soundbridge is clinically proven to provide benefit for both patient groups. |
| 162596 | Pacing Importers Pty Ltd – AP404 Audio Processor – Middle ear implant sound processor | 19/06/2009 | The intended purpose of this device is for use in patients who have mild to severe hearing impairment and cannot achieve success or adequate benefit from traditional therapy. It is indicated for both sensorineural and mixed and conductive hearing loss. The AP is the external component of the Soundbridge System. The Soundbridge is clinically proven to provide benefit for both patient groups. |

Australian Therapeutic Goods Administration database accessed 7/09/2009. Available at:

[https://www.ebs.tga.gov.au/ebs/ANZTPA](http://www.ebs.tga.gov.au/ebs/ANZTPAR/PublicWeb.nsf/cuDevices?OpenView)R[/PublicWeb.nsf/cuDevices?Op](http://www.ebs.tga.gov.au/ebs/ANZTPAR/PublicWeb.nsf/cuDevices?OpenView)enView

HL: hearing loss; VORP: vibrating ossicular replacement prosthesis; AP audio processor

#### Table 3 Items relating to middle ear implants listed by the FDA

| **FDA number** | **FDA Label name** | **Date Approved** | **Indication** |
| --- | --- | --- | --- |
| P990052 | Vibrant Soundbridge | 31/08/2000 | The Vibrant Soundbridge is intended for use in adults, 18 years of age or older, who have a moderate to severe sensorineural hearing loss and desire an alternative to an acoustic hearing aid. |
| P010023 | SOUNDTEC® Direct  Drive Hearing System | 7/09/2001 | This device is indicated in adults, 18 years of age or older, who have a moderate to severe sensorineural hearing loss and desire an alternative to an acoustic hearing aid. |

United States Food and Drug Administration database accessed 7/09/2009. Available at: <http://www.fda.gov/default.htm>

On 17 March 2010 the FDA approved the Esteem®-Hearing ImplantTM (Envoy Medical Corporation, Saint Paul, Minneapolis, USA) (http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm204956.htm).

Other MEI devices identified in the international literature include the SOUNDTEC® Direct Drive Hearing System (SoundTec, Inc., Oklahoma City, OK, USA), the CarinaTM Fully Implantable Hearing Device (Otologics, LLC, Boulder, Colorado, USA), the Rion Implantable hearing aid (RION Co., Ltd., Tokyo, Japan) and the Totally Implantable Cochlea Amplifier (CochlearTM, Melbourne, Australia). Although these devices are not registered with the TGA they shall be considered a part of this report, as the Advisory Panel considers the devices to be essentially the same as the device produced by Progressive Medical (above). Differences between these devices in terms of mode of action and surgical technique shall be highlighted in the results section (Table 21).

**Current reimbursement arrangement**

There are no current MBS listings for MEI procedures.

**Outcome measurement tools**

A wide variety of outcome tools are utilised in the available literature. A brief description of the most common tools is provided below.

**Hearing device performance**

 **Functional gain:** a measure of the benefit provided by the MEI. It is calculated by determining the difference between the unaided preoperative and aided postoperative pure-tone average thresholds (Lefebvre et al 2009).

 **Profile of Hearing Aid Performance (PHAP)**: a questionnaire comprising

66 items scored in seven subscales. The PHAP attempts to capture an individual’s experiences when using their hearing aid (Cox 1997).

 **Profile of Hearing Aid Benefit (PHAB)**: this questionnaire builds upon the PHAP by including responses to the items from the point of view of an

unaided listener. The listener’s opinion of the benefits and costs of their hearing aid use is shown by determining the difference between responses for “with my hearing aid” and ‘without my hearing aid’ (Cox 1997).

The PHAP and the APHAB are generally considered too lengthy for many clinical applications. In response, the Abbreviated Profile of Hearing Aid Benefit was developed (Cox 1997).

The **Abbreviated Profile of Hearing Aid Benefit (APHAB)** comprises 24 items scored in four subscales:

 Ease of Communication (EC): ease or difficulty of communicating under relatively favourable conditions

 Reverberation (RV): communication in reverberant settings (e.g. classrooms)

 Background Noise (BN): communication in settings with high background noise levels

 Aversiveness (AV): the unpleasantness of environmental sounds

(Cox 1997).

Each item is answered in the context of ‘without my hearing aid’ and ‘with my hearing aid’, thus providing a score for both unaided and aided listening and allowing the calculation of a score for benefit (Cox 1997).

 **Client-oriented scale of improvement:** an outcome measure comprising two phases. In the first phase the individual with hearing loss identifies listening situations that he/she would like to have improved with new amplification. The hearing aid is then fitted. In the second phase the change in hearing function for the identified listening situation is recorded (National Acoustic Laboratories 2000-05).

**Speech outcomes**

 **Speech detection level:** the softest level at which a person detects (rather than understands) speech sounds. The person is not required to recognise the sound, but rather to acknowledge its presence (Lalwani 2008).

 **Speech reception threshold:** the lowest intensity level at which a patient can correctly repeat 50 per cent of common bisyllabic words like ‘hotdog’ or

‘baseball’ (Cummings 2005).

 **Speech intelligibility in quiet:** determined using monosyllabic words presented at the conversational level (between 40-65 dB SPL). One error is counted each time a phoneme is mispronounced or not repeated, and the final score is converted to a percentage (Truy et al 2008).

 **Speech Perception in Noise (SPIN):** developed in the 1970s and revised in the mid 1980s, the test consists of eight lists of 50 sentences. The test items are the last words in these sentences. The SPIN test allows separate

scores for understanding of sentences that contain contextual information and of those that do not.

Sentences are accompanied by a background noise and can be presented at various signal/noise ratios (Elliott 1995; Gelfand 2009; Smoski 2008).

**Patient related outcomes**

 **Glasgow Benefit Inventory (GBI):** a measure of a patient’s change in health status as a result of a health care intervention, which was developed especially for otorhinolaryngological interventions. The GBI is an 18-item questionnaire which is completed by the patient after the intervention either at home or in the outpatient clinic (Robinson et al 1996).

 **Hearing Device Satisfaction Scale (HDSS):** a questionnaire which was developed by the company Symphonix Devices. Comprising 21 questions, the HDSS assesses a listener’s satisfaction associated with use of their hearing device and their hearing ability in various listening situations. Listener satisfaction is rated upon a five-point response scale, from very satisfied to very dissatisfied (Uziel et al 2003).

 **Hough Ear Institute Profile (HEIP):** a questionnaire assessing a person’s satisfaction with their current hearing device. This measures several aspects including tinnitus, masking effect, sound quality perceptions, presence of feedback and occlusion; and device preference (Matthews 2002).

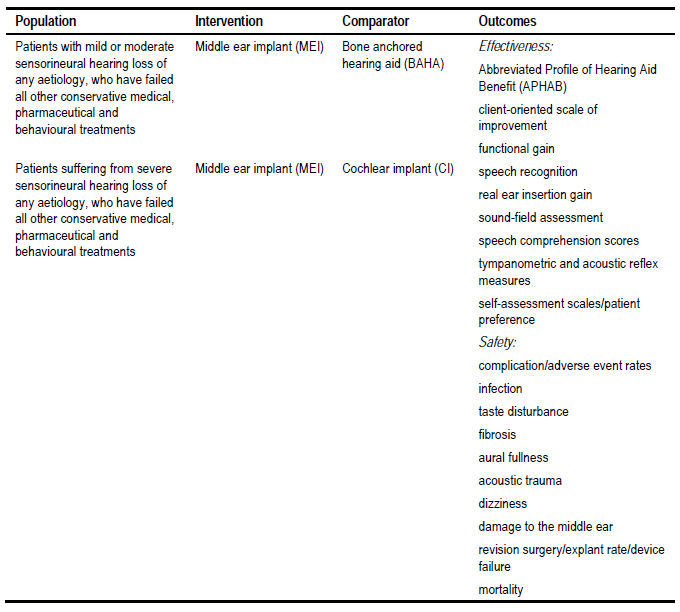
 **Gothenburg Profile:** a tool which permits quantification of subjectively experienced hearing disability (e.g. speech intelligibility, localisation skills) and any accompanying social and emotional handicap (e.g. social relationships, self-confidence) (Zenner et al 2003).

## Approach to assessment

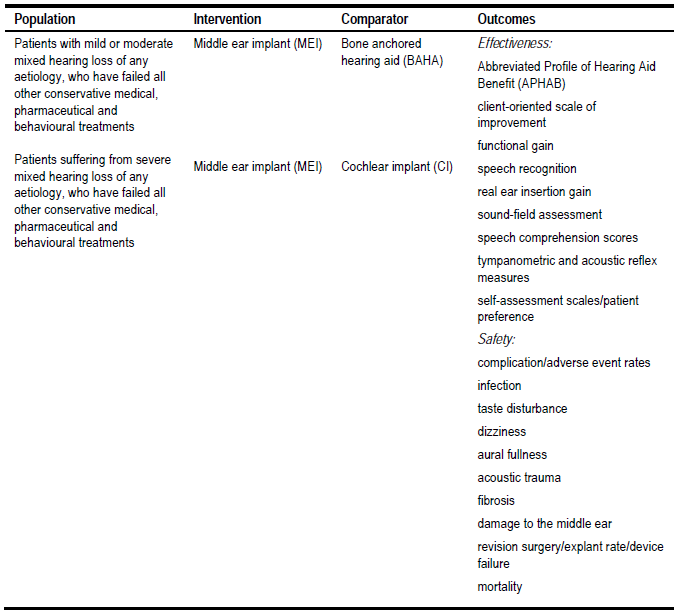
### Review of literature

PICO (population, intervention, comparator, outcome) criteria were developed with the assistance of the Advisory Panel (Table 4, Table 5, Table 6). These criteria assisted in specifying the search strategy.

#### Table 4 PICO criteria for middle ear implants for sensorineural hearing loss

****

#### Table 5 PICO criteria for middle ear implants for mixed hearing loss



#### Table 6 PICO criteria for middle ear implants for conductive hearing loss

**Population Intervention Comparator Outcomes**

Patients suffering from established stabilised conductive hearing loss of any aetiology, who have failed all other conservative medical, pharmaceutical and behavioural treatments

Middle ear implant (MEI) Bone anchored hearing aid (BAHA)

*Effectiveness:*

Abbreviated Profile of Hearing Aid

Benefit (APHAB)

client-oriented scale of improvement

functional gain speech recognition real ear insertion gain

sound-field assessment

speech comprehension scores tympanometric and acoustic reflex

measures

self-assessment scales/ patient preference

*Safety:*

complication/adverse event rates infection

taste disturbance dizziness

aural fullness acoustic trauma fibrosis

damage to the middle ear

revision surgery/explant rate/device failure

mortality

The PICO criteria have defined five patient subgroups dependent on the type and severity of hearing loss (two each for sensorineural and mixed and one for conductive hearing loss). The effectiveness results have been presented according to these populations where possible.

**Clinical questions**

1. In patients with mild or moderate SNHL is the MEI more effective than the

BAHA?

2. In patients with severe SNHL is the MEI more effective than the CI?

3. In patients with mild or moderate MHL is the MEI more effective than the

BAHA?

4. In patients with severe MHL is the MEI more effective than the CI?

5. In patients with CHL is the MEI more effective than the BAHA?

Relevant electronic databases were searched to identify relevant studies and reviews for the period between database inception and August 2009. Searches were conducted via PubMed, EMBASE, the Cochrane Library and Current Contents. The search terms used included MeSH terms and textwords:

**MeSH terms**

Hearing loss, conductive/ OR Hearing loss, sensorineural/ OR Hearing loss, noise-induced/ OR Hearing loss, mixed conductive-sensorineural/ OR Hearing loss, high frequency/ OR Hearing loss, unilateral/ OR Hearing loss, bilateral/ OR Hearing loss, central/ OR Deafness/ OR Retrocochlear Diseases/ OR Ear, middle/ OR Ossicular prosthesis OR Otologic surgical procedures.

**Textwords**

((Middle and ear) or (ossicle\* or ossicular or malleus or incus\* or stapes or eardrum or tympanic membrane)) and (implant\* or transduce\* or stimulat\* or aid or equipment or appliance\* or device\* or prosthe\*) or Soundbridge or Floating Mass Transducer or FMT or Vibrating Ossicular Prosthesis or Envoy or Esteem or SoundTec or Middle Ear Transducer or Carina or MET Ossicular Stimulator or TICA or Totally Implantable Cochlea\* Amplifier or Rion or

e-type.

**Inclusion criteria**

Case reports were not considered for effectiveness outcomes, but were included for the assessment of safety outcomes for the MEI. Where comparative

evidence did not inform on the safety of the BAHA or CI, case series information for these interventions was included and assessed. This information was limited to recent studies (post-2006) of consecutive patients with populations of 20 or more, and a minimum of six months follow-up. The detailed inclusion criteria which were applied to all retrieved studies are in Table

7.

#### Table 7 Inclusion criteria for identification of relevant studies

**Characteristic Criteria**

Publication type *Effectiveness:* systematic reviews and clinical studies including randomised and non- randomised comparative studies and case series will be included. Non-systematic reviews, case reports, letters, editorials, and animal, in-vitro and laboratory studies will be excluded.

*Safety:* systematic reviews and clinical studies including randomised and non-randomised comparative studies, case series and case reports will be included. Non-systematic reviews, letters, editorials, and animal, in-vitro and laboratory studies will be excluded.

Patient Male or female patients diagnosed with mild, moderate or severe sensorineural, mixed or conductive hearing loss who are refractory to medical or surgical management.

Intervention Middle ear implant

Comparator *Patients with mild or moderate sensorineural hearing loss:* bone anchored hearing aid

*Patients with severe sensorineural hearing loss:* cochlear implant

*Patients with mild or moderate mixed hearing loss:* bone anchored hearing aid

*Patients with severe mixed hearing loss:* cochlear implant

*Patients with mild, moderate or severe conductive hearing loss:* bone anchored hearing aid

Outcome *Effectiveness:* APHAB, client-oriented scale of improvement, patient-related outcomes, quality of life

*Safety:* Complication/adverse event rate, mortality, revision surgery

Language1 Non-English articles will be excluded unless they appear to provide a higher level of evidence than English language articles. Translation of such articles will significantly increase the timeframe of the review.

**Literature databases**

Initial eligibility on the basis of the collated study citations was conservatively determined by one reviewer (i.e. if unclear from the abstract, or if the reviewer was unsure, the full text paper was ordered). One reviewer then assessed each of the retrieved full text articles for eligibility, with another assessing those over which there was doubt. When consensus could not be reached, a third reviewer independently assessed the paper in question and the majority decision

prevailed. A list of studies which met the inclusion criteria but were subsequently excluded from the report is provided at Appendix E. The bibliographies of all included studies were hand-searched for any relevant references which may have been missed through the literature searching (pearling).

**Data extraction**

Data were extracted by one researcher and checked by a second using standardised data extraction tables developed a priori. Data were only extracted and reported if stated in the text, tables, graphs of figures of the study, or if they could be accurately extrapolated from the data presented.

**Description and methodological quality of included studies**

The evidence presented in the selected studies was assessed and classified using the dimensions of evidence defined by the National Health and Medical Research Council (NHMRC 2000). These dimensions (Table 8) consider important aspects of the evidence supporting a particular intervention and include three main domains: strength of the evidence, size of the effect and

relevance of the evidence. The first domain is derived directly from the literature

identified as informing a particular intervention. The last two require expert clinical input as part of its determination.

#### Table 8 Evidence dimensions

**Type of evidence Definition**

Strength of the evidence

Level

Quality

Statistical precision

The study design used, as an indicator of the degree to which bias has been eliminated by design.\*

The methods used by investigators to minimise bias within a study design.

The *P*-value or, alternatively, the precision of the estimate of the effect. It reflects the degree of certainty about the existence of a true effect.

Size of effect The distance of the study estimate from the “null” value and the inclusion of only clinically important effects in the confidence interval.

Relevance of evidence The usefulness of the evidence in clinical practice, particularly the appropriateness of the outcome measures used.

\*See Table 9

The three sub-domains (level, quality and statistical precision) are collectively a measure of the strength of the evidence. The designations of the levels of evidence are shown in Table 9.

#### Table 9 Designations of levels of evidence\* according to type of research question

#### (including tablenotes) (NHMRC 2000)

**Level Intervention §**

I \* A systematic review of level II studies

II A randomised controlled trial

III-1 A pseudorandomised controlled trial

(ie alternate allocation or some other method) III-2 A comparative study with concurrent controls:

Non-randomised, experimental trial †

Cohort study

Case-control study

Interrupted time series with a control group

III-3 A comparative study without concurrent controls: Historical control study

Two or more single arm study ‡

Interrupted time series without a parallel control group

IV Case series with either post-test or pre-test/post-test outcomes

Tablenotes

\* A systematic review will only be assigned a level of evidence as high as the studies it contains, excepting where those studies are of level II evidence.

§ Definitions of these study designs are provided on pages 7-8 How to use the evidence: assessment and application of scientific evidence (NHMRC 2000).

† This also includes controlled before-and-after (pre-test/post-test) studies, as well as indirect comparisons (i.e. utilise A vs

B and B vs C, to determine A vs C).

‡ Comparing single arm studies i.e. case series from two studies.

Note 1: Assessment of comparative harms/safety should occur according to the hierarchy presented for each of the research questions, with the proviso that this assessment occurs within the context of the topic being assessed. Some harms are rare and cannot feasibly be captured within randomised controlled trials; physical harms and psychological harms may need to be addressed by different study designs; harms from diagnostic testing include the likelihood of false positive and false negative results; harms from screening include the likelihood of false alarm and false reassurance results.

Note 2: When a level of evidence is attributed in the text of a document, it should also be framed according to its corresponding research question e.g. level II intervention evidence; level IV diagnostic evidence.

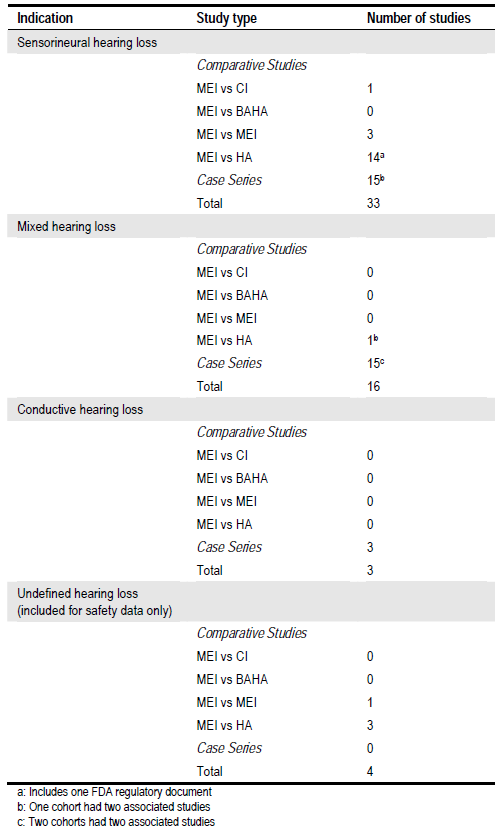
**Expert advice**

An Advisory Panel with expertise in hearing loss was established to evaluate the evidence and provide advice to MSAC from a clinical perspective. In selecting members for advisory panels, MSAC's practice is to approach the appropriate medical colleges, specialist societies and associations and consumer bodies for nominees. Membership of the Advisory Panel is provided at Appendix B.

## Results of assessment

### Descriptive characteristics of included studies

#### Table 10 Included middle ear implant studies



Effectiveness data for the MEI in comparison with the BAHA, CI or HA were extracted from comparative studies. Further effectiveness data for the MEI alone were extracted from comparative studies and case series studies. Effectiveness data were not extracted from case reports due to the inherent risk of bias in these studies.

Studies which included patients with profound hearing loss, but did not report outcomes for these patients separately, were excluded from the report. Those studies in which individual profound patient data could be excluded were included in the report.

**Studies for assessment of safety and effectiveness**

**Middle ear implant compared with the cochlear implant**

**Safety**

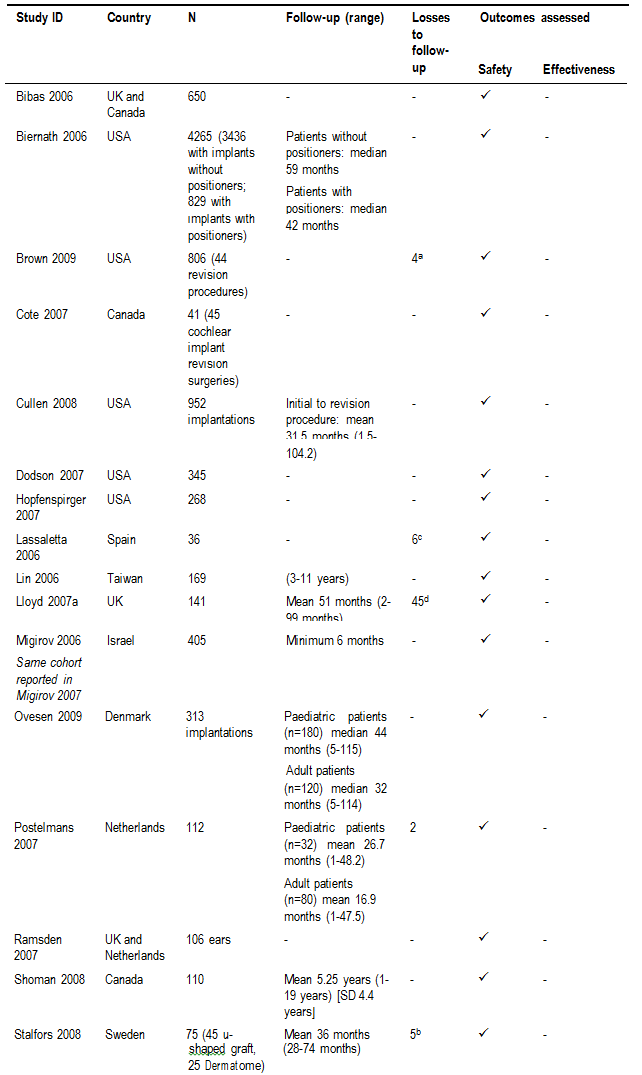
One study which compared the CI with the MEI was identified; however, this study did not include any safety data (Verhaegen et al 2008). A total of 20 case series were eligible for inclusion in this report (Table 11). No studies reported upon the severity of hearing loss in their cohorts.

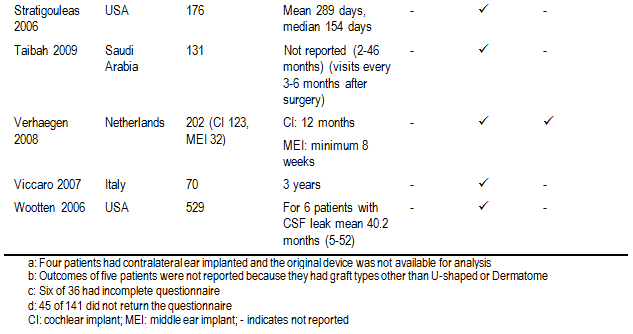
**Effectiveness**

The systematic literature search identified one comparative study that directly compared the effectiveness of the MEI to the CI (Verhaegen et al 2008) (Table

11). All patients had SNHL of undefined severity.

#### Table 11 Included studies for cochlear implant





**Middle ear implant compared with the bone anchored hearing aid**

**Safety**

No studies comparing the safety of both the BAHA and the MEI were identified. A total of seven case series which assessed the safety of BAHA implantation in a total of 619 patients were eligible for inclusion in this report (Table 12). A variety of hearing losses were treated including SNHL (Badran et al 2009; Gillett et al

2006; Yuen et al 2009), CHL (Badran et al 2009; Davids et al 2007; Gillett et al

2006; Lloyd et al 2007), MHL (Badran et al 2009; Lloyd et al 2007) and undefined hearing loss (Tjellstrom et al 2007). Four of the six studies stated that patients had either mild or moderate hearing loss (Badran et al 2009; Davids et al 2007; Lloyd

et al 2007; Yuen et al 2009). The remaining studies did not provide any data on hearing loss severity.

**Effectiveness**

No comparative studies which directly compared the effectiveness of the MEI

and the BAHA in patients with SNHL, MHL or CHL could be identified.

Table 12 Included studies for bone anchored hearing aid

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Study ID** | **Country** | **N** | **Follow-up** | **Losses to follow-up** | **Out** | **comes assessed** |
|  |  |  |  |  | **Safety** | **Effectiveness** |
| Badran 2009 | UK | 176 (178 BAHA) | Mean 50 months | 2 |  | - |
| Davids 2007 | Canada | 40 | - | - |  | - |
| Gillett 2006 | UK | 63 | > 6 months | Questionnaire |  | - |
|  |  |  |  | returned by |  |  |
|  |  |  |  | 41/59  patientsa |  |  |
| Lloyd 2007 | UK | 85 ears implanted | Mean 4.5 years | - |  | - |
| Stalfors 2008 | Sweden | 75 | Mean 36 months | 5b |  | - |
| Tjellstrom | Sweden | 144 | Mean 22.3 | 3 |  | - |
| 2007 |  |  | months |  |  |  |
| Yuen 2009 | Canada | 34 | Mean 22.4 | 13c |  | - |
|  |  |  | months |  |  |  |

a: Only 38 or 40 replies were recorded for some questions because some patients felt questions were not applicable to them b: Outcomes of five patients were not reported because they had graft types other than U-shaped or Dermatome

c: Complete 1-year data were only available for 21 patients

BAHA: bone anchored hearing aid; - indicates not reported

**Middle ear implant**

**Safety**

A total of 49 studies reported safety outcomes in patients receiving MEI. Twenty seven studies assessed patients with SNHL (Table 13), 15 studies assessed patients with MHL (Table 14) and three studies assessed patients with CHL (Table 15). An additional four studies assessed safety outcomes in patients with hearing loss that was not clearly defined (Table 16; Table 19). All patients who received the MEI had mild, moderate or severe hearing loss.

**Effectiveness**

Effectiveness outcomes after MEI implantation were reported for a total of 450 patients. For SNHL three level III studies were included (Snik et al 2004; Snik and Cremers 2004a; Snik et al 2007). In these studies all patients received the MEI and further comparisons were made either between different MEIs or different attachment types. Nine level IV studies were also assessed (Table 13) including

two studies reporting upon one cohort (Mosnier et al 2008; Sterkers et al 2003).

For MHL and CHL only level IV studies were identified and assessed. For CHL four studies reported upon two cohorts, with each cohort reported upon twice (Suzuki et al 1994 and Suzuki et al 1995; Yanagihara et al 1997 and Yanagihara et al 2001).

Effectiveness outcomes were not included for an identified study which assessed the effectiveness of MEI yet did not clearly state the type of hearing loss (Stieve et al 2009).

#### Table 13 Included studies for middle ear implant for sensorineural hearing loss

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study ID** | **Country** | **N** | **Follow-up** | **Losses to follow-up** | **HL**  **severity** | **MEI implanted** | **Outcomes Assessed** | |
|  |  |  |  |  |  |  | **Safety** | **Effectiveness** |
| Level III |  |  |  |  |  |  |  |  |
| Snik 2004 | Netherlands | 13 | >12 months | - | Severe | VSB n=8 and |  |  |
|  |  |  |  |  |  | MET n=5 |  |  |
| Snik 2004a | Netherlands | 13 | Minimum 6 months | 2 | Moderate | VSB |  |  |
| Snik 2007 | Netherlands | 23 | 12 months | 1 | Moderate | VSB n=14 and  MET n=9 | - |  |
| Level IV |  |  |  |  |  |  |  |  |
| Barbara  2009 | Italy | 6 | - | 3 | Moderate | Envoy Esteem |  |  |
| Cremers  2008 | Netherlands | 1 | 6 years after original surgery; 26 months after | 0 | Moderate | VSB |  | - |
|  |  |  | revision |  |  |  |  |  |
| Fisch 2001 | Switzerland; Netherlands; Germany; Italy; France; UK (10 | 47 | 12 weeks | 0 | Mild to severe | VSB |  |  |
|  | centres) |  |  |  |  |  |  |  |
| Foyt 2006 | USA | 8 | MI group mean 2 years; traditional group mean | 0 | Moderate | VSB |  |  |
|  |  |  | 3.7 years |  |  |  |  |  |
| Garin 2002 | Belgium (2 centres) | 9 | Mean 15.6 months | 0 | Moderate to severe | VSB | - |  |
| Snik 1999 | Netherlands | 7 | Minimum 2 months after AP fitting | 0 | Moderate to severe | VSB |  |  |
| Snik 2000 | Netherlands | 6 | 8-19 months | - | Moderate | VSB |  | - |
| Snik 2006 | Netherlands | 21 | 6-24 months | 4 | - | VSB n=13 and  MET n=8 |  |  |
| Sterkers | France (21 | 125 | 3-5 months | 30 | Mild to | VSB |  |  |
| 2003 | centres) |  |  |  | severe |  |  |  |
| *Same cohort reported in Mosnier* |  |  |  |  |  |  |  |  |
| *2008* |  |  |  |  |  |  |  |  |
| Todt 2005 | Germany | 2 | - | 0 | - | VSB |  | - |
| Vincent  2004 | France (several centres) | 39 | 16 months | - | Moderate | VSB |  | - |
| Zenner  2000 | Germany | 20 | 6 months | 1 | Moderate to severe | TICA |  |  |
| Zenner | Germany | 13 | Minimum 6 | - | Moderate | TICA |  |  |
| 2003 |  |  | months |  | to severe |  |  |  |
| Zenner  2004 | Germany | 20 | 6 months | 1 | Moderate to severe | TICA |  |  |

MET: Otologics Middle Ear Transducer; TICA: Totally Implantable Cochlea Amplifier; VSB: Vibrant Soundbridge; - indicates not reported

#### Table 14 Included studies for middle ear implant for mixed hearing loss



Table 15 Included studies for middle ear implant for conductive hearing loss

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study ID** | **Location** | **N** | **Follow-up** | **Losses to follow-up** | **HL severity** | **MEI**  **implanted** | **Outcomes assessed** | |
|  |  |  |  |  |  |  | **Safet y** | **Effectiveness** |
| LEVEL IV |  |  |  |  |  |  |  |  |
| Frenzel  2009 | Germany; Italy | 7 | 8 months | - | Moderate | VSB |  |  |
| Siegert | Germany; | 5 | Minimum 3 | - | Moderate to | MET |  |  |
| 2007 | USA |  | months |  | severe |  |  |  |
| Tringali  2008 | France | 1 | 15 months | 0 | Severe | Carina |  | - |

MEI: middle ear implant; MET: Otologics Middle Ear Transducer; VSB: Vibrant Soundbridge; - indicates not reported

#### Table 16 Included studies for middle ear implant for undefined hearing loss

**Study ID Location N Follow-up Losses to follow-up**

**HL**

**severity**

**MEI**

**implanted**

**Outcomes assessed**

**Safety Effectiveness**

LEVEL III Stieve

2009

Germany 34 Minimum 12 months

- - MET n=19  - and VSB

n=15

MEI: middle ear implant; MET: Otologics Middle Ear Transducer; VSB: Vibrant Soundbridge; - indicates not reported

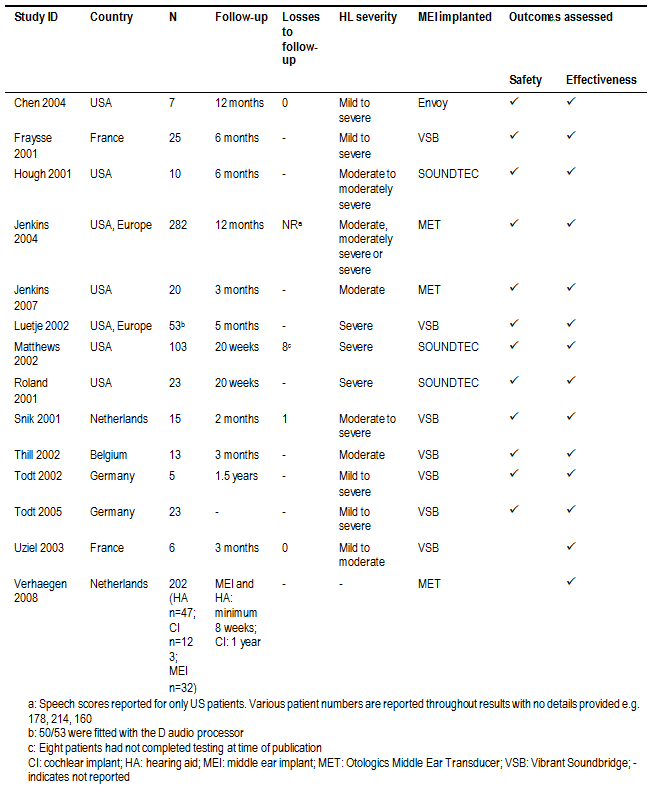
**Middle ear implant vs external hearing aids**

Expert opinion from the Advisory Panel suggested that the external hearing aid (HA) should not be considered as a direct comparator for the purposes of this report. From the clinical decision flow charts (see Figure 2, Figure 3, Figure 4) it can be seen that patients must have failed a trial of external hearing aid before being considered for MEI. However, the Advisory Panel also recognised that if MEI became more widely available some patients may consider it an attractive option and that demand for MEI may be greater than current BAHA or CI procedures. Therefore the Advisory Panel felt that a brief comparison of the HA and the MEI may prove to be informative, and that a discrete assessment should be provided.

A total of 18 comparative studies were identified which directly compared the effectiveness of the MEI and the HA, and these were analysed by hearing loss type and severity. Fourteen studies assessed patients with mild to severe SNHL (Table 17) and one assessed patients with severe MHL (Table 18). No comparative studies informed upon patients with CHL.

Effectiveness outcomes were not included for three identified studies which assessed the effectiveness of MEI vs HA yet did not clearly state the type of hearing loss (Kodera et al 1994; Schmuziger et al 2006; Truy et al 2008).

#### Table 17 Comparative studies for the middle ear implant versus hearing aid in sensorineural hearing loss



#### Table 18 Comparative studies for the middle ear implant versus hearing aid in mixed hearing loss

**Study ID Location N Follow-up Losses to follow-up**

**HL**

**severity**

**MEI**

**implanted**

**Outcomes assessed**

**Safety Effectiveness**

Tos 1994

*Same cohort reported in Caye- Thomasen*

*2002*

Denmark 9 3 months 3 Severe Heide  

System

HL: hearing loss; MEI: middle ear implant; - indicates not reported

#### Table 19 Comparative studies for the middle ear implant versus hearing aid in undefined hearing loss

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study ID** | **Location** | **N** | **Follow-up** | **Losses to follow-up** | **HL**  **severity** | **MEI implanted** | **Outcomes assessed** | |
|  |  |  |  |  |  |  | **Safet y** | **Effectiveness** |
| Kodera 1994 | Japan | 6 | - | - | Moderate | Rion device |  | - |
| Schmuziger  2006 | Switzerland | 24 | Mean 42 months | 4 | Moderate | VSB |  | - |
| Truy 2008 | France | 6 | 3 months | - | Moderate | VSB |  | - |
|  |  |  | of MEI use |  |  |  |  |  |

MEI: middle ear implant; VSB: Vibrant Soundbridge; - indicates not reported

In addition to the identified level III studies one Food and Drug Authority (FDA) regulatory document was identified (Symphonix Devices, Incorporated 2000) (Table 20). This document assessed the effectiveness of MEI compared with the HA in a cohort of 54 patients with mild to moderate SNHL. As this document

has not been published in a peer-reviewed journal and was authored by an MEI manufacturing company, the data from this cohort have been presented separately throughout the report.

#### Table 20 FDA regulatory document for middle ear implant for sensorineural hearing loss

**Study ID Country N Follow-up Losses to follow- up**

**HL**

**severity**

**MEI**

**implanted**

**Outcomes assessed**

**Safety Effectiveness**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Symphonix | USA | 54 | 5 months | 1a | Moderate | VSB with the  |  |
| Devices, |  |  | postoperatively |  | to severe | D audio |  |
| Incorporated, |  |  | plus an |  |  | processor |  |
| 2000 |  |  | additional 6 |  |  |  |  |
|  |  |  | weeks to |  |  |  |  |
|  |  |  | acclimatise to |  |  |  |  |
|  |  |  | the Vibrant D  audio processor |  |  |  |  |

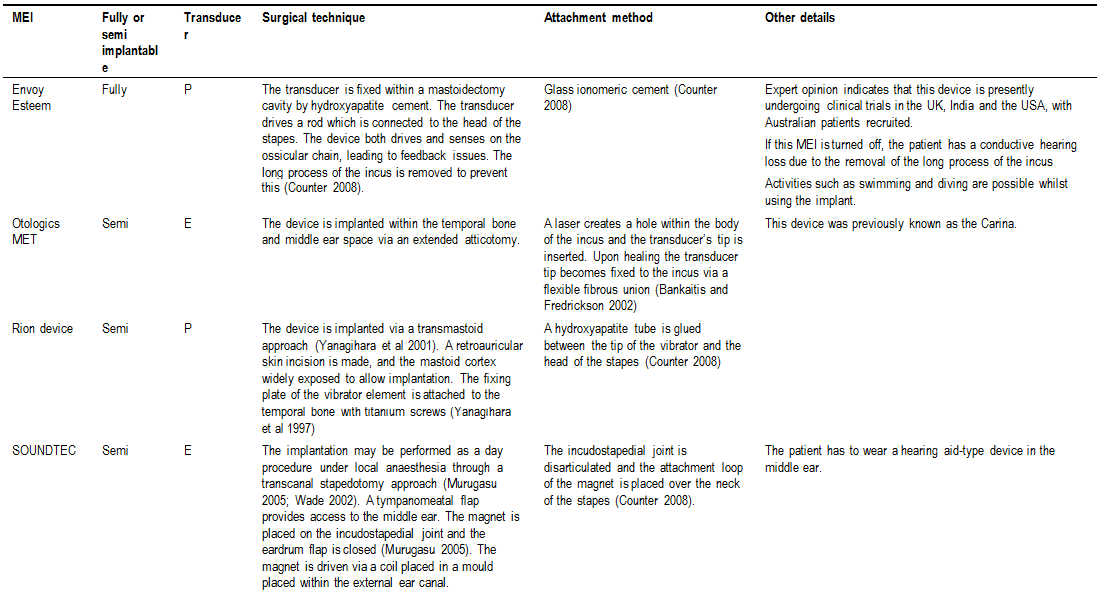
a One patient’s device did not activate and patient was not evaluated

HL: hearing loss; MEI: middle ear implant; VSB: Vibrant Soundbridge

**Variation in middle ear implant devices**

The comprehensive literature searching identified several different MEl devices (fable 21). Each device aimed to directly drive the ossicular chain through vibrations produced by either piezoelectric or electromagnetic transducers (l<:.ulkarni and Hartley 2008). The major characteristics of the different devices have been summarised in Table 21.

#### Table 21 Middle ear implant devices identified in the literature search



TICA Fully P The device is implanted via a postauricular incision and mastoidectomy (Wood 2002). The transducer is placed in the mastoid cavity and coupled to the incus. The sensor is implanted subcutaneously in the posterior bony wall of the auditory canal. The battery and audio processor are enclosed in a capsule which, similar to a cochlear implant receiver, is implanted subcutaneously behind the ear in a recess created in the temporal bone (Zenner et al 2003).

A titanium coupling rod is connected to the long incus process or the incus body. This attachment may be accompanied by a reversible malleus neck dissection, which produces an

air-bone gap to intensify the volume and suppress feedback (Zenner 2000; Zenner et al 2004)

Activities such as swimming and diving are possible whilst using the implant (Zenner et al 2003).

If the device is turned off, the patient has a conductive hearing loss due to the dissection of the malleus neck.

Vibrant

Soundbridge

Semi E The VORP is implanted under the skin posterior- superior to the pinna at a 45° angle to the ear canal. The VORP’s electromagnetic transducer is electrically connected to the internal receiver (Wade 2002).

The FMT is attached to the incus by a titanium clip, which is formed around the long process of the incus with a specialised forceps (Counter 2008).

This MEI is considered to be reversible as attachment does not permanently alter the middle ear (Arthur 2002).

FMT attachment may lead to erosion of the incus (Hough et al

2001)

E: electromagnetic; P: piezoelectric; FMT: floating mass transducer; MEI: middle ear implant; MET middle ear transducer; TICA: Totally Implantable Cochlea Amplifier; VORP vibrating ossicular prosthesis

Expert clinical opinion advises that the placement of any MEI device in the middle ear, regardless of attachment method, may lead to a conductive hearing loss. Additionally the above table represents the typical attachment method for each MEI. Nine included studies reported that atypical measures, such as bone cement or fascia, were necessary to ensure MEI stability (Colletti et al 2009; Cremers et al 2008; Dumon et al 2009; Frenzel et al 2009; Lefebvre et al 2009; Snik and Cremers 2004a; Streitberger et al 2009; Todt et al 2002). Further, nine included studies reported upon instances in which the MEI device itself was modified (Table 22). Generally the titanium clip of the MEI was removed or shortened to permit implantation, and this was mostly performed in patients with mixed or conductive hearing loss due to particular anatomic constraints. Hence, differences in components and attachment may either occur between the six

identified different MEI devices (Table 21) or between patients receiving the same

MEI (Table 22).

#### Table 22 Studies which reported modification of the middle ear implant

|  |  |  |
| --- | --- | --- |
| **Study ID** | **MEI type** | **Modification** |
| SNHL |  |  |
| Cremers 2008 | VSB | The grip of the FMT was removed and the FMT was attached to the stapes head with SerenoCem |
| MHL |  |  |
| Colletti 2009 | VSB | The titanium clip of the FMT was cut |
| Cuda 2009 | VSB | The titanium clip of the FMT was cut |
| Lefebvre 2009 | MET | A modified TORP was clipped to the end of the transducer |
| Streitberger 2009 | VSB | The titanium clip of the FMT was cut |
| Tos 1994 | Heide system | The hydroxylapatite shaft of the PORP was cut nearly totally off |
| CHL |  |  |
| Frenzel 2009 | VSB | The titanium clip of the FMT was removed |
| Siegert 2007 | MET | The coupling device was modified. A prosthesis specially produced for this study by Kurz Co., Munich, Germany, was used for sound transmission |

CHL: conductive hearing loss; FMT: floating mass transducer; MEI: middle ear implant; MET: Otologics Middle Ear Transducer; MHL: mixed

hearing loss; SNHL: sensorineural hearing loss; TORP: total ossicular replacement prosthesis; VSB: Vibrant Soundbridge

### Systematic reviews

No systematic reviews which assessed the middle ear implant were identified. Two horizon scanning documents were identified (Canadian Coordinating Office for Health Technology Assessment (CCOHTA) 2003; Comite d’Evaluation et de Diffusion des Innovations Technologiques (CEDIT) 2002).

One document was published in France in 2002 and provided a concise overview of the MEIs which were available in that market at the time (CEDIT 2002). Neither a search strategy nor a list of references was provided. The devices considered were the Vibrant Soundbridge, the Otologics Middle Ear Transducer and the SOUNDTEC Direct Drive Hearing System, all of which are also considered in MSAC Application 1137. The document stated that the MEI is for

‘…adults suffering from stable hearing loss, which is bilateral and relatively symmetrical, without fluctuation, in the mild (41 to 70 dB) to severe range (71 to

90 dB) with normal tympanometry, normal middle ear anatomy with no previous history of chronic middle ear disease or middle ear surgery, no inner ear disorder, and who are dissatisfied with a hearing aid.’ The population considered by this document is more limited than that considered in MSAC Application 1137. A simple economic analysis was performed which stated that the cost of hospital- based management of the MEI in adults is approximately €10,000, of which 56 per cent was the cost of the device itself. This document noted that the undebatable medical indications for receiving the MEI are skin pathology or anatomical abnormality in the ear canal, due to the fact that this makes the use of the HA more difficult. It recommended the establishment of the defined audiological parameters for the use of the MEI.

The second document was published in Canada in 2003 and assessed the devices which were available at that time (CCOHTA 2003). A search strategy was not provided; however, a list of references was provided which included FDA information, clinical studies and newspaper articles. This document was primarily concerned with the SOUNDTEC Direct System, and briefly referred to the Vibrant Soundbridge and Otologics Middle Ear Transducer technologies, all of which are included in MSAC Application 1137. The population considered in this document was broad, comprising adult patients with moderate to severe deafness due to disorders of the auditory nerve. The SOUNDTEC manufacturer provided the cost of the device for the Canadian market. No further analysis was performed. The document concluded that semi-implantable MEI may be appropriate for those with moderate to severe hearing loss whom also experience difficulties with conventional hearing aids. It also highlighted the need for clinicians to undertake manufacturer-provided, specialised training in the use of the device.

Searches were also conducted for current ongoing trials, which are listed at

Appendix F.

### Critical appraisal

A total of 24 comparative studies (NHMRC level III) were identified and included in this report (Table 63). One study compared the CI with the MEI in patients with SNHL of undefined severity (Verhaegen et al 2008). No additional comparative studies assessed the MEI versus the CI or BAHA. Three

comparative studies assessed the MEI with a further internal comparison (Snik et al 2004; Snik and Cremers 2004a; Snik et al 2007). These studies assessed the VSB MEI versus the MET MEI (Snik et al 2004; Snik et al 2007) and the crimping attachment alone versus crimping attachment plus cement (Snik and Cremers

2004a).

Nineteen comparative studies assessed the MEI versus the external HA. Thirteen of these studied patients with SNHL, two studied patients with MHL, and four studied patients with CHL. One additional comparative cohort assessed the MEI versus the HA in patients with SNHL (Symphonix Devices Incorporated 2000). This study was an FDA regulatory document which was produced by an MEI device manufacturer. This study was not reported in a peer-reviewed journal and has been presented separately throughout this report.

A total of 35 level IV studies were identified and included in this report (Table 64; Table 65; Table 66). Fifteen studies assessed the MEI in patients with SNHL; 16 assessed the MEI in patients with MHL; and three assessed the MEI in patients with MHL. The safety data from one additional case series which studied patients with undefined hearing loss was also included (Stieve et al 2009).

Critical appraisal of the level III and level IV studies has been performed separately, to reflect the methodological differences between these study types.

**Critical appraisal of level III studies**

A summary of the quality of the 25 comparative studies included in the report is reported in Table 63, and briefly outlined below. The criteria used were based on the CONSORT statement of Altman et al (2001).

**Participants**

One study reported retrospective data collection (Verhaegen et al 2008); however, the remaining 24 studies did not report study design. Six of the included studies reported that participants were consecutively enrolled (Fraysse et al 2001; Hough et al 2001; Luetje et al 2002; Matthews 2002; Snik and Cremers 2004a; Uziel et al

2003).

Eleven studies reported explicit inclusion and exclusion criteria (Chen et al 2004; Fraysse et al 2001; Hough et al 2001; Jenkins et al 2004; Jenkins et al 2007; Luetje et al 2002; Matthews 2002; Snik and Cremers 2001; Symphonix Devices, Incorporated 2000; Verhaegen et al 2008; Zenner et al 2004), while eight studies reported only inclusion criteria (Roland et al 2001; Snik et al 2007; Snik et al 2004; Snik and Cremers 2004a; Thill et al 2002; Todt et al 2005; Todt et al 2002; Truy et al 2008). Six studies failed to report inclusion or exclusion criteria (Caye- Thomasen et al 2002; Kodera et al 1994; Schmuziger et al 2006; Stieve et al 2009; Tos et al 1994; Uziel et al 2003).

Inclusion criteria used to recruit participants generally included symmetrical sensorineural hearing loss and chronic, therapy-resistant external otitis. Patients were generally excluded if they suffered from any physical, psychological or emotional disorder that would interfere with surgery or the ability to perform on test or rehabilitation procedures, or diseases of the EAC/middle ear/temporal bone.

**Interventions and outcomes**

The interventions were well described, with most of the 25 studies detailing both the implantation procedure and the implant utilised. However, studies generally lacked detail with regards to the technical settings of the implant. Only four

studies reported upon this issue (Luetje et al 2002; Snik and Cremers 2001; Snik et al 2007; Snik et al 2004).

Most studies provided objective measurements of success in terms of functional gain/speech recognition and some included subjective measures of success such as the APHAB and quality of life scales (either validated or non-validated). Adverse events, if present, were generally adequately described.

**Statistical methods**

Statistical tests were generally employed in most of the studies, with 15 out of 25 comparative studies providing significance levels (*P-*values).

**Follow-up and losses to follow-up**

The length of follow-up amongst the 21 studies that reported follow-up ranged from two months to 9.5 years. Four studies did not report the length of follow-up (Hough et al 2001; Kodera et al 1994; Snik et al 2007; Todt et al 2005). Ten of the studies reported losses to follow-up (Caye-Thomasen et al 2002; Matthews 2002; Schmuziger et al 2006; Snik et al 2007; Snik and Cremers 2004a; Snik and Cremers

2001; Symphonix Devices, Incorporated 2000; Tos et al 1994; Uziel et al 2003; Zenner et al 2004), with eight studies detailing reasons for these losses (Matthews

2002; Schmuziger et al 2006; Snik et al 2007; Snik and Cremers 2004a; Snik and Cremers 2001; Symphonix Devices, Incorporated 2000; Uziel et al 2003; Zenner et al 2004).

**Critical appraisal of level IV studies**

An appraisal of the quality of the 29 level IV studies included in this report for effectiveness and safety is reported below and represented in Table 64; Table 65; and Table 66.

**Participants**

Of the 29 level IV studies selected for inclusion, seven were retrospective while the remaining were prospective studies. Sample sizes ranged from one to 125 patients; however, the majority of studies (22 out of 29) had less than 20 patients. Most studies provided clear inclusion criteria; however, only one study provided an exclusion criterion for patient selection.

**Interventions and outcomes**

The interventions were well described, with most studies (22 of 29 studies) detailing both the implantation procedure and the implant utilised. However, studies generally lacked detail with regards to the technical settings of the implant.

Most studies provided objective measurements of success in terms of hearing gain/speech recognition and some included subjective measures of success such as quality of life scales (validated and non-validated). Adverse events, if present, were generally adequately described.

**Statistical methods**

Statistical tests were generally not employed in most of the studies, with only five out of 29 studies providing significance levels (*P*-values).

**Follow-up and losses to follow-up**

Follow-up durations varied substantially between studies, from two to 62 months. Losses to follow-up were generally rare, with most studies successfully retaining patients. However, it is important to note that most studies had small sample

sizes.

### Is it safe?

One comparative study assessed patients who received either CI or MEI

implantation; however, this study did not include any safety data (Verhaegen et al

2008). Twenty three comparative studies did provide safety data; however, as these studies did not assess the comparators of interest for this report (CI or BAHA), they were unable to inform on the relative safety of these procedures compared with MEI implantation (Table 63). Therefore, safety has been reported in an absolute manner.

Throughout the safety section event rate has been reported in two manners, both of which may be at risk of bias. The rate has been presented as a proportion of patients in the studies which specifically reported this outcome, which may be an over-inflated representation of the outcome, especially for rare events. The rate has also been presented as a proportion of the total patient number in all studies included for safety. This may be an under-representation of some outcomes, such as common outcomes which may not have been of interest in all studies (such as mild pain or infection).

**Middle ear implant**

Fifty studies reported upon safety outcomes in a total of 1222 patients receiving MEI. These patients had mild, moderate or severe SNHL, MHL or CHL. The fifty included studies comprised comparative studies (which assessed the VSB versus the MET; crimping attachment alone versus crimping attachment plus

cement; and MEI versus the HA), case series, case reports and an FDA regulatory cohort. Safety data were included from four studies in which the HL indication was undefined (Kodera et al 1994; Schmuziger et al 2006; Stieve et al 2009; Truy

et al 2008). Overall, patient populations ranged from one (Cremers et al 2008; Dumon 2007; Foyt and Carfrae 2006; Tringali et al 2009; Tringali et al 2008) to

282 (Jenkins et al 2004). Follow-up ranged from two months (Snik and Cremers

2001) to eight years (Mosnier et al 2008).

**Mortality**

Only three studies reported on mortality in their patient cohort (Mosnier et al

2008; Schmuziger et al 2006; Snik et al 2006). Seven patients were reported to have died in a total of 170 patients (4.1 per cent) (Table 23). This equates to an incidence of 0.57 per cent across all 1222 patients who received MEI. Where stated reported deaths were not attributed to the implantation; however, one study did not provide any detail (Mosnier et al 2008).

#### Table 23 Mortality after MEI implantation

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study ID** | **N** | **n** | **Rate where reported %** | **Rate across total number of patients %** | **Details** |
| Mosnier 2008 | 125 | 5 | 4% | 0.4% | - |
| Schmuziger 2006 | 24 | 1 | 4.1% | 0.08% | unrelated causes |
| Snik 2006 | 21 | 1 | 4.8% | 0.08% | manifested a degenerative disease |
| - indicates not reported |  |  |  |  |  |

**Adverse events**

Table 24 details the reported adverse events which accompanied MEI implantation. Several studies reported upon adverse events or issues which were addressed and subsequently resolved by the device manufacturers, such as inability to charge the device (Jenkins et al 2007); upside-down implantation due to unclear packaging (Fisch et al 2001); and device failure (Mosnier et al 2008). These incidents have not been included in the calculations of adverse events as they occurred in the versions of devices which are clearly no longer available.

Event rate has been reported in two manners, both of which may be at risk of bias. The rate has been presented as a proportion of patients in the studies which specifically reported this outcome, which may be an over-inflated representation of the outcome, especially for rare events. The rate has also been presented as a proportion of the total patent number in all studies included for safety. This may be an under-representation of some outcomes, such as common outcomes which may not have been of interest in all studies (such as mild pain or infection).

Table 24 Adverse outcomes in 1222 patients receiving MEI implant

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Outcome** | **Number of studies** | **Patients N=** | **Incidence n=** | **Rate where reported (%)** | **Rate across total number of patients (%)** |
| Technical adverse events |  |  |  |  |  |
| Facial nerve damage | 8 | 296 | 3 | 1% | 0.2% |
| Chorda tympani nerve damage | 7 | 381 | 38 | 10% | 3.1% |
| Extrusion | 7 | 122 | 4e | 3.3% | 0.3% |
| Migration | 5 | 98 | 4b | 4.1% | 0.3% |
| Device malfunction or failure | 8 | 312 | 11i | 3.5% | 0.9% |
| Electromagnetic interference | 3 | 117 | 18 | 15.3% | 1.5% |
| Insufficient gain | 4 | 76 | 20c | 26.3% | 1.6% |
| Clinical adverse events |  |  |  |  |  |
| Stroke | 1 | 9 | 1\* | 11.1% | 0.1% |
| TM perforation | 4 | 189 | 9g | 4.8% | 0.7% |
| TM retraction | 3 | 79 | 2 | 2.5% | 0.2% |
| Infection | 9 | 282 | 8a | 2.8% | 0.7% |
| Pain | 6 | 225 | 30 | 13.3% | 2.5% |
| Haematoma | 4 | 151 | 15h\*\* | 9.9% | 1.2% |
| Tinnitus | 7 | 349 | 7f | 2% | 0.6% |
| Vertigo | 5 | 274 | 14 | 5.1% | 1.1% |
| Aural fullness | 3 | 199 | 45 | 22.6% | 3.7% |
| Wound healing difficulties | 4 | 54 | 0 | 0% | 0% |
| Other | 13 | 418 | 60j | 14.4% | 4.9% |
| Device explant for other reasons | 4 | 178 | 6d | 3.4% | 0.5% |

\*This outcome was reported in a level III study with limited reporting. Expert clinical opinion suggests that MEI implantation causation is unlikely

\*\* One patient was 14 years of age at implantation. The haematoma developed in the surgical site postoperatively and required minor surgical intervention to clean and evacuate. This follow-up included a 10-day course of antibiotics to prevent infection. Following the revision and antibiotics, the postoperative outcome was satisfactory with no further complications

a: One patient’s MEI was explanted due to non-device related infection

b: One migration was due to MRI and revision surgery was required to reattach the MEI. One patient’s MEI was removed and replaced by a homograft incus; two further patients underwent revision surgery

c: Two MEIs were explanted; one additional MEI was explanted and replaced with a CI

d: Two MEIs were explanted due to patient demand (these were functioning devices), one was explanted due to acute psychiatric problems, one was explanted due to a retroauricular fistula, one was explanted due to a developing perisynaptic defect and was replaced with a CI, one was removed due to ineffective repeated surgery

e: Three cases were revised with soft tissue coverage and healed without difficulty; one not reported f: One MEI was explanted due to tinnitus

g: One perforation successfully repaired with patch; one perforation repaired by fascia; seven not reported h: Two patients required revision surgery

i: One MEI was explanted, one MEI was replaced

j: Revision in eight patients, unsuccessful revision in one patient

Twelve studies with a total of 145 patients reported that there were no complications (Colletti et al 2009; Cuda et al 2009; Dumon et al 2009; Frenzel et al 2009; Lefebvre et al 2009; Siegert et al 2007; Snik and Cremers 1999; Suzuki et al 1995; Todt et al 2002; Todt et al 2005; Venail et al 2007; Vincent et al 2004). Three studies included children (Dumon et al 2009; Frenzel et al 2009; Tringali et al 2009). No adverse events were reported in children in two of these studies (Dumon et al 2009; Frenzel et al 2009). Tringali et al (2009) was a case study which assessed a 14-year-old child. This child developed a haematoma in the surgical site postoperatively and required minor surgical intervention to clean and evacuate. This follow-up included a 10-day course of antibiotics to prevent infection. Following the revision and antibiotics, the postoperative outcome was

reported to be satisfactory with no further complications. No association was made between the patient’s age and this complication.

Several studies reported upon serious adverse events such as stroke and nerve damage (Table 24). One patient was reported to have had a stroke and was lost to follow-up (Tos et al 1994). Tos et al (1994) provided very limited reporting and did not include any information regarding this patient’s age or comorbidities. Expert clinical opinion endorsed by the Advisory Panel felt that there was insufficient clinical information on which to assess whether the stroke was related

to the MEI implantation process. Eight studies reported upon facial nerve damage

(Cuda et al 2009; Fisch et al 2001; Fraysse et al 2001; Mosnier et al 2008; Sterkers et al 2003; Schmuziger et al 2006; Symphonix Devices, Incorporated, 2000; Thill et al 2002), with most reporting that there was no damage to the facial nerve (or no facial palsy). A total of three patients (1 per cent of patients in studies which reported this outcome; 0.2 per cent across all MEI patients) suffered facial palsy after MEI implantation (Fraysse et al 2001; Symphonix Devices, Incorporated

2000). All three patients suffered from SNHL and received a VSB implant. One case of palsy resolved spontaneously six weeks after onset while the other two cases were resolved with medical management. One study recommended the routine use of a facial nerve monitor to help prevent facial nerve damage (Fraysse et al 2001).

Seven studies reported upon damage to the chorda tympani nerve (Fisch et al

2001; Matthews 2002; Mosnier et al 2008; Sterkers et al 2003; Schmuziger et al

2006; Snik et al 2007; Symphonix Devices, Incorporated 2000). Seven studies used the VSB device and the remaining study used the SOUNDTEC device. The

chorda tympani was severed in six patients, while possible damage to the chorda tympani occurred in 32 patients and was characterised by transient taste disturbance. Several studies reported that this resolved over time (Fisch et al 2001; Mosnier et al 2008; Symphonix Devices, Incorporated 2000).

Two studies reported that the MEI was removed and replaced with a cochlear implant (Colletti et al 2009; Todt et al 2005). In one patient this exchange was due to insufficient gain from the VSB MEI (Colletti et al 2009) and in the second patient was due to a developing perisynaptic defect (Todt et al 2005). No other studies reported replacement of the MEI with either the BAHA or the CI. However, in an additional study one patient discontinued use of their Heide system MEI due to misfitting, pain and apoplexia and subsequently used a HA in the operated ear (Caye-Thomasen et al 2002).

**Residual hearing**

In addition to these adverse events MEI implantation may cause a decline in residual hearing due to either the noise generated during the surgical procedure (Snik and Cremers 2000) or mass loading of the ossicular chain. For example the Otologics MET includes a push rod which may compromise the mobility of the ossicular chain, whereas the VSB may affect residual hearing primarily by the added mass (Stieve et al 2009). Additionally, manipulation of the ossicular chain may introduce CHL.

Most included studies reported upon residual hearing loss and considered a mean threshold change of greater than 5 dB across all frequencies to be clinically significant (Fisch et al 2001). Twenty four studies reported that no significant decline in mean residual hearing loss occurred after MEI implantation (Cuda et al

2009; Dumon 2007; Dumon et al 2009; Fisch et al 2001; Foyt and Carfrae 2006; Fraysse et al 2001; Frenzel et al 2009; Hough et al 2001; Jenkins et al 2004; Jenkins et al 2007; Lefebvre et al 2009; Luetje et al 2002; Matthews 2002; Roland

et al 2001; Sterkers et al 2003; Siegert et al 2007; Stieve et al 2009; Streitberger et al

2009; Suzuki et al 1995; Thill et al 2002; Todt et al 2004; Todt et al 2005; Tringali et al 2009; Truy et al 2008). However, thirteen studies reported significant declines in mean residual hearing loss after MEI implantation (Table 25). MEI

implantation in patients with CHL did not have a significant negative effect upon residual hearing.

#### Table 25 Description of studies in which there was a mean residual hearing loss

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study ID** | **Patients N** | **HL severity** | **MEI device** | **Location of MEI attachment** |
| SNHL |  |  |  |  |
| Barbara 2009 | 3 | Moderate | Envoy | Incus and stapes |
| Chen 2004 | 7 | Mild to severe | Envoy | Incus and stapes |
| Mosnier 2008 | 125 | Mild to severe | VSB | - |
| Symphonix 2000 | 54 | Moderate to severe | VSB | - |
| Todt 2002 | 5 | Mild to severe | VSB | Incus |
| Snik 2004a | 13 | Moderate | VSB | Incus |
| Vincent 2004 | 39 | Moderate | VSB | - |
| Zenner 2003 | 13 | Moderate to severe | TICA | Incus |
| MHL |  |  |  |  |
| Colletti 2006 | 7 | Severe | VSB | Round window |
| Suzuki 1995 | 19 | - | Rion device | - |
| Undefined |  |  |  |  |
| Schmuziger 2006 | 24 | Moderate | VSB | - |
| Stieve 2009 | 34 (19 MET, 15  VSB) | - | MET and VSB | Mastoid and incus |

CHL: conductive hearing loss; HL: hearing loss; MEI: middle ear implant; MHL: mixed hearing loss; MET: Otologics Middle Ear Transducer;

SNHL: sensorineural hearing loss; - indicates not reported

Several studies also reported clinically significant changes in the hearing of individual patients after MEI implantation (Table 26). Again, implantation did not negatively affect the residual hearing of patients with CHL.

#### Table 26 Individual patients with significant residual hearing loss after middle ear implantation

**Incidence of significant hearing loss**

a: Not published in a peer-reviewed journal

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study ID** | **N patients** | **HL severity** | **MEI type** | **n** | **%** |
| SNHL |  |  |  |  |  |
| Fraysse 2001 | 25 | Mild to severe | VSB | 5 | 20% |
| Luetje 2002 | 50 | Severe | VSB | 2 | 4% |
| Snik 2001 | 14 | Moderate to severe | VSB | 1 | 7.1% |
| Symphonix 2000a | 54 | Moderate to severe | VSB | 2 | 3.7% |
| Fisch 2001 | 47 | Mild to severe | VSB | 7b | 14.9% |
| Snik 1999 | 7 | Moderate to severe | VSB | 1 | 14.3% |
| Sterkers 2003 | 125 | Mild to severe | VSB | 3 | 2.4% |
| Vincent 2004 | 39 | Moderate | VSB | 6 | 15.4% |
| MHL |  |  |  |  |  |
| Caye-Thomasen 2002 | 6 | Severe | Heide system | 4 | 66.7% |
| Cuda 2009 | 8 | Moderate | VSB | 1 | 12.5% |
| Dumon 2009 | 13 | Moderate | VSB | 1 | 7.6% |
| Suzuki 1989 | 9c | Moderate | Rion device | 3 | 33.3% |
| Suzuki 1995 | 16 | - | Rion device | 2d | 12.5% |
| Undefined |  |  |  |  |  |
| Schmuziger 2006 | 15 | Moderate | VSB | 4 | 26.7% |

b: Patients with significant changes in unaided thresholds in the implanted ear did not demonstrate changes to the same degree in the nonimplanted ear. Thus, these changes cannot be attributed to systematic influences such as anaesthesia, measurement error, or patient-specific influences.

c: 10 ears in nine patients

d: Patients continued to use the device all the time

MEI: middle ear implant; MHL: mixed hearing loss; SNHL: sensorineural hearing loss; VSB: Vibrant Soundbridge

**Air-bone gap**

As placement of the MEI may affect conductive hearing, the presence and extent of a postoperative air-bone gap (ABG) may inform further upon the safety of implantation. One study reported upon postoperative ABG in patients with SNHL (Foyt and Carfrae 2006). The mean ABG (4 dB) is consistent with the equivalent air and bone conduction present in SNHL, suggesting that a conductive hearing loss was not introduced to these patients. Five studies reported upon the ABG in patients with MHL (Colletti et al 2009; Dumon 2007;

Dumon et al 2009; Streitberger et al 2009; Suzuki et al 1989) (Table 27). Generally MEI implantation reduced the ABG, suggesting that conductive hearing was improved. Two studies reported overclosure of the ABG, which occurs when the postoperative AC threshold is lower than the preoperative BC threshold (Fucci et al 1998). The ABG was overclosed by 15 to 17 dB (Colletti et al 2009; Streitberger et al 2009). Overall, where reported, mean ABG was improved after implantation.

#### Table 27 Air bone gap after MEI implantation in patients with MHL

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study ID** | **MEI type** | **Site of attachment** | **Mean**  **preoperative ABG** | **Mean postoperative**  **ABG** | **Improvement or decline** |
| Colletti 2009 | VSB | Round window | 38.28 dB [SD 11.9] | -19.38 [SD 7.5] | Overclosure |
| Cuda 2009 | VSB | Round window | 23.6 dB | 32.3 dB | Decline |
| Dumon 2007 | VSB | Incus | 32 dB | 11 dB | Improvement |
| Dumon 2009 | VSB | Round window/incus | 17 dB | 20 dB | Decline |
| Streitberger 2009 | VSB | Round window niche, stapes footplate, stapes superstructure, cochlear fenestration | - | Not reported (overclosure of the ABG of approximately 17 dB) | Overclosure |
| Suzuki 1989 | Rion device | - | 36.6 dB | 3.5 dB | Improvement |

ABG: air bone gap; dB: decibels; MEI: middle ear implant; SD: standard deviation; VSB: Vibrant Soundbridge; - indicates not reported

In two studies the ABG worsened postoperatively (Cuda et al 2009; Dumon et al

2009). In one study the AC threshold was significantly worse after MEI implantation (*P*<0.05) although there was no significant change in BC threshold (Cuda et al 2009). The authors attributed this to a modification of the transfer function of the middle ear induced by the FMT on the round window membrane. In the second study a variety of mixed hearing losses presented, but only patients with chronic otitis whose MEI was implanted on the round window (n=2) displayed this decline (Dumon et al 2009). However, in a further study in which all patients had chronic otitis media and round window implantation of the MEI, the ABG was over-closed by 15 dB (Colletti et al 2009).

The stapedius reflex occurs when the stapedius muscle contracts in reaction to a loud sound. The reflex thresholds refer to the softest intensity levels that can trigger the response. Two studies reported upon stapedius reflex thresholds (Luetje et al 2002; Snik and Cremers 2000). One study found that in patients with recordable acoustic reflexes before surgery, there were no absent reflexes at the same frequencies at three months postactivation (Luetje et al 2002). The second study reported that an increase in stapedius reflex thresholds was generally found shortly after surgery (Snik and Cremers 2000).

**Summary of safety for middle ear implant**

No comparative evidence was available to inform on safety of the MEI compared with either the BAHA or CI. Comparative, case series and case report data on a total of 1222 patients who received MEI were available. The comparative studies compared the VSB with the MET, or the MEI with the HA, and drew no safety-related comparisons between these devices. There were no deaths associated with MEI implantation. Most adverse events were relatively rare and of low severity. Serious adverse events such as facial nerve damage were reported to have occurred rarely (0.2 per cent across all MEI patients). Damage to the chorda tympani nerve was reported more commonly (3.1 per cent across all MEI patients); however, some instances of taste disturbance were

reported to have been transient and to have resolved over time. Technical complications related to the device, including device malfunction, migration, or insufficient gain were relatively rare (0.3 to 1.6 per cent across all patients).

Residual hearing loss after MEI implantation was reported upon by most studies, with

13 studies reporting that patients suffered significant declines in mean residual hearing loss after MEI implantation.

Expert clinical opinion suggests that some safety issues may be more specific to children. Across the identified studies only one adverse event, a haematoma, was reported to have occurred in a child. No association was made between the age of this patient and the complication.

**Cochlear implant**

One comparative study included patients who received either MEI or CI implantation (Verhaegen et al 2008). However this study did not provide any safety data. In the absence of comparative data, all safety outcomes for CI implantation were sourced from case series. Twenty case series with a total of

9704 participants met the inclusion criteria and were included (Table 11). Several studies implanted the CI only in children (Bibas et al 2006; Biernath et al 2006; Cullen et al 2008; Hopfenspirger et al 2007; Lin et al 2006) and the remaining studies implanted either in adults, or in both adults and children. None of the included case series reported upon the severity of hearing loss. Due to the indications for this procedure it is likely that some patients were afflicted with profound hearing loss.

The included case series were all retrospective; however, all enrolled patients consecutively. Sixty two patients were lost to follow-up; however, 45 of these patients were lost in one study through a failure to return the questionnaire (Lloyd et al 2007a). Where reported, follow-up ranged from one to 115 months.

Event rate has been reported in two manners, both of which may be at risk of bias. The rate has been presented as a proportion of patients in the studies which specifically reported this outcome, which may be an over-inflated representation of the outcome, especially for rare events. The rate has also been presented as a proportion of the total patent number in all studies included for safety. This may be an under-representation of some outcomes, such as common outcomes which may not have been of interest in all studies (such as mild pain or infection).

**Mortality**

One study with a total of 4265 participants reported upon patient mortality, and found that two children died after CI implantation due to bacterial meningitis (Biernath et al 2006).

#### Table 28 Clinical adverse events in 9704 patients receiving a cochlear implant

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Outcome** | **Number of studies** | **Patients**  **N=** | **Incidence n=** | **Rate where reported (%)** | **Rate across total number**  **of patients (%)** |
| Meningitis | 4 | 5380 | 44a | 0.82% | 0.45% |
| MRSA in radical cavity | 1 | 313 | 1 | 0.32% | 0.01% |
| Cerebrospinal fluid leak | 4 | 1320 | 13b | 0.98% | 0.13% |
| Dural injury | 1 | 952 | 2c | 0.21% | 0.02% |
| Chorda tympani nerve sectioning | 1 | 141 | 14 | 9.92% | 0.14% |
| Mastoiditis | 3 | 750 | 15d | 2% | 0.15% |
| Infection | 10 | 2637 | 48e | 1.82% | 0.49% |
| Perilymphatic fistula | 2 | 450 | 2f | 0.44% | 0.02% |
| Implant rejection | 1 | 952 | 1 | 0.11% | 0.01% |
| Taste disturbance | 4 | 522 | 49g | 9.39% | 0.50% |
| Abscess formation | 5 | 1656 | 14h | 0.85% | 0.14% |
| Haematoma | 2 | 457 | 2i | 0.43% | 0.02% |
| Temporal muscle spasms with trismus | 1 | 45 | 1j | 2.2% | 0.01% |
| Flap/wound healing difficulties | 4 | 1839 | 48k | 2.6% | 0.49% |
| Injury to the EAC | 1 | 952 | 2 | 0.21% | 0.02% |
| Tympanic membrane perforations | 2 | 243 | 6l | 2.47% | 0.06% |
| Vestibular symptoms | 1 | 110 | 64m | 58.18% | 0.66% |
| Light-headedness | 1 | 110 | 31n | 28.18% | 0.32% |
| Unsteadiness | 2 | 286 | 55o | 19.23% | 0.57% |
| Myringoplasty | 1 | 131 | 1p | 0.76% | 0.01% |
| Tinnitus | 4 | 1276 | 13 | 1.02% | 0.13% |
| Vertigo | 4 | 328 | 31q | 9.45% | 0.32% |
| Other | 7 | 2646 | 42r | 1.7% | 0.43% |
| Revision surgery (other reasons) | 1 | 176 | 6 (reason not documented) | 3.41% | 0.06% |

a: 41 episodes of bacterial meningitis in 38 children, two of whom died; one case of meningitis in a patient with cerebrospinal fluid (CSF)

gusher at time of surgery, the patient recovered completely with the implant in place. Two cases resulted in electrode migration

b: One had CSF leak intraoperatively while the bony well was drilled and was immediately sealed (healed well with good outcomes); one delayed CSF leak; five CSF gushers, six all controlled at initial surgery (three required only electrode insertion, hyperventilation, and cochleostomy packaging with fascia or periosteum. In two cases cochleostomy packaging was augmented with partial or complete middle ear packing. One also required packing of the Eustachian tube and supplemental fibrin glue. No patient required lumbar puncture, and all patients received perioperative antibiotics)

c: Two repaired intraoperatively

d: One required mastoidectomy and hardware removal and consequently elected not to undergo reimplantation; one patient treated with mastoidectomy

e: One subsequent to a fall and necessitated removal of the implant; eight wound infections (three cases required antibiotic therapy), two infections around the pedestal site; implant removal in 21 cases and followed with successful reimplantation in 14 cases; one wound infection and device extrusion requiring explantation; one flap infection requiring oral antibiotics and topical ointment and resolved after four weeks; one pseudomonas infection which was most likely due to intra-operative fluid contamination (controlled with medical and surgical treatment but device explanted due to reoccurrence of infection); one infection as a result of injured skin at the receiver site (implant explanted after failure of debridement of the wound and extensive antimicrobial therapy)

f: One led to revision surgery

g: Three managed by observation, 18 patients had long-term taste disturbance, one resolved after first postoperative visit

h: 10 required revision surgery, one was an incision stitch abscess which resolved with oral antibiotics and topical wound care

i: One was a subdural haematoma which required burr-hole craniotomy and evacuation of the haematoma without permanent neurological sequelae

j: Healed well with good outcomes

k: 24 required revision; three managed with rotational flap, frequent dressing changes and oral antibiotics

l: TM perforations in four children after acute otitis media, all healed spontaneously after medication administration m: Preoperatively 53 patients had symptoms and postoperatively 64 patients showed symptoms

n: Preoperatively 23 patients had symptoms and postoperatively 31 patients had symptoms

o: In one study preoperatively 35 patients had symptoms and postoperatively 51 patients had symptoms. In the other study one patient had symptoms with device use only while three patients had transient postoperative vestibulopathy

p: No details provided

q: Shoman preoperatively 30, postoperatively 40 (counted as 10 in the table). Viccaro n=8, seven occurred in the implanted side and one in the opposite side (was overcome via surgery in six, one patient presented chronic symptoms regardless of the manoeuvres performed)

r: Led to explantation n=5; led to contralateral implantation n=5; led to revision n=7; led to reimplantation n=3

#### Table 29 Technical adverse events in 9704 patients receiving a cochlear implant

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Outcome** | **Number of studies** | **Patients N=** | **Incidence n=** | **Rate where reported (%)** | **Rate across total number**  **of patients (%)** |
| CI migration | 4 | 2037 | 6a | 0.3% | 0.06% |
| Device exposure | 2 | 1119 | 4b | 0.36% | 0.04% |
| Facial nerve paralysis | 5 | 1388 | 8l | 0.36% | 0.08% |
| Non-use of CI | 2 | 762 | 2c | 0.26% | 0.02% |
| Electrode migration | 3 | 1464 | 4d | 0.4% | 0.04% |
| Electrode extrusion | 3 | 1128 | 9e | 0.8% | 0.09% |
| Stimulator extrusion | 1 | 45 | 1f | 2.2% | 0.01% |
| Cable erosion | 1 | 45 | 1 | 2.2% | 0.01% |
| Misplacement of electrode | 6 | 1939 | 15g | 0.8% | 0.15% |
| Device failure | 8 | 3278 | 126h | 3.83% | 1.3% |
| Unable to replace electrode | 1 | 952 | 2i | 0.2% | 0.02% |
| Electrode kinked in cochlea | 1 | 952 | 1i | 0.1% | 0.01% |
| Fragility and weight of the processor | 1 | 36 | 1 | 2.8% | 0.01% |
| Poor discrimination | 1 | 36 | 1 | 2.8% | 0.01% |
| Magnet issues | 3 | 1247 | 5j | 0.4% | 0.05% |
| Device breakage | 1 | 169 | 1k | 0.6% | 0.01% |
| Electrode malfunction | 1 | 112 | 1 | 0.9% | 0.01% |
| Partial insertion | 1 | 57 | 7 | 12.3% | 0.07% |

a: Three required repositioning, two repositioning not required, one required revision surgery

b: Two due to device infection and one due to development of bony overgrowth under the implant; one in a diabetic patient with a skin defect, whose device was explanted

c: One non-user due to abnormal cochlear nerve adaption, one no details

d: Two not reported, one required replacement; one required complete drill-out procedure due to fibrosis and ossification of the basal turn of the cochlea

e: Included one child

f: Extrusion at wound in paediatric patient

g: Seven required revision, five required repositioning h: Six re-implanted; 27 revised

i: Required revision

j: Three patients magnet was displaced and required revision surgery k: Required reimplantation

l: Five were transient facial palsy (three of which were reported to have resolved), one was a result of thermal injury where initially a

House-Brackmann II-IV progressed to a VI/VI and then recovered to a II/IV.

**Meningitis**

A total of 44 episodes of meningitis, including 41 episodes in children, were reported (Biernath et al 2006; Brown et al 2009; Ovesen and Johansen 2009) (Table 28). Twenty seven (71 per cent) of the children with meningitis had CI implantation with positioners (wedges inserted next to the CI in earlier device models which were voluntarily removed from the market in 2002 in response to reports received by the FDA). A 2002 study indicated that the incidence of meningitis among patients who had received a CI with a positioner remained higher than the incidence among those whose CI did not have a positioner for the duration of 24 months post-implantation follow-up (Reefhuis et al 2003). This finding was supported by the results in Biernath et al (2006), as the incidence rate of ≥24 month post-implantation meningitis for children with positioners was 450 cases per 100,000 person-years (95% CI 165-980 cases per 100,000 person-years) compared with none for those without positioners. However, six children also

had factors other than a CI that might have predisposed them to meningitis such as inner ear malformations, CSF leak, previous meningitis, history of recurrent

otitis media, tympanostomy tubes, and acute otitis media at the time of presentation.

**Soft failure**

Several studies described ‘soft failure’ as an adverse event (Brown et al 2009; Cullen et al 2008; Lin et al 2006; Ramsden et al 2007). Generally, soft failure encompassed events of nonauditory stimulation such as unwanted twitching of the facial nerve, pain and dizziness (Ramsden et al 2007). A total of 70 adverse events were attributed to soft failure (0.72 per cent of all patients who received CI). Several of these events were managed by remapping (switching off certain electrodes) or through medication.

Some adverse events were reported which appeared to be related to the patients’ anatomy. One patient with an absent auditory nerve required revision surgery (Cullen et al 2008). Difficult insertion of the CI was encountered in 15 patients (0.8 per cent of patients in studies which reported this outcome; 0.15 per cent of all patients who received CI). Two children experienced a foreign body reaction while one child had an allergic reaction to the CI, and all three patients required revision surgery (Migirov et al 2007). One adult also had a foreign body reaction and required revision surgery (Migirov et al 2007).

**Wound healing**

One study provided extensive information on wound reactions and classified these using the system described by Holgers et al (1988) (Stalfors and Tjellstrom

2008). Briefly, the scale comprises 0=no irritation, 1=slight redness, 2=red and moist tissue, 3=red and moist with granulation tissue, 4=revision of skin penetration necessary (Lloyd et al 2008). These were analysed with respect to the surgical technique employed used when implanting the CI (Table 30). As the dermatome method creates an elevated skin graft without hair follicles, patients may find it easier to maintain the implant site area. The U-shaped graft had 19.6 per cent more skin reaction episodes than the dermatome group, but this was not significantly different (*P*=0.14).

#### Table 30 Skin reaction grades according to surgical technique

**Dermatome n=25 U-graft n=45**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Grade** | **Observations** | **%** | **Observations** | **%** |
| 0 | 86 | 95 | 234 | 91.4 |
| 1 | 1 | 1.1 | 18 | 7.0 |
| 2 | 3 | 3.3 | 4 | 1.6 |
| 3 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 |
| Total | 90 | 100 | 256 | 100 |

**Summary of safety for cochlear implant**

Twenty case series with a total of 9704 patients were available to inform of the absolute safety of CI for hearing loss. This increased number of patients compared with MEI study information reflects the more established nature of CI as a treatment for hearing loss.

Several intracranial adverse events which were reported in CI patients were absent in

MEI patients. Importantly meningitis was reported in 44 CI patients, two of whom

died. Most of the patients with meningitis were children. Two CI patients were reported to have received dural damage during drilling of the receiver/stimulator well which was repaired intraoperatively (Dodson et al 2007). This study suggested that CIs which require a smaller well to accommodate the receiver/stimulator necessitate less drilling near the dura, which is likely to lead to fewer dural injuries. Cerebrospinal fluid leak was also reported exclusively in CI patients (13 patients).

Conversely, several events were reported more frequently in MEI than in CI patients. The incidence of tympanic membrane perforation was higher in the MEI patients (0.7 per cent for all MEI patients compared with 0.06 per cent for all CI patients), most likely due to the techniques used for MEI implantation. Haematomae also occurred more frequently in MEI than in CI patients (1.2 per cent for all MEI patients compared

with 0.02 per cent for all CI patients). Extrusions also occurred more frequently in MEI

than in CI patients.

Rates of damage to the chorda tympani and the facial nerves were similar between the CI and MEI patients. Additionally, the CI and MEI devices appeared to be similar in terms of failure rates.

None of the included CI studies reported upon residual hearing outcomes after implantation. This may be because the patients considered for CI implantation are likely to have severe or profound HL; therefore, any further deterioration in hearing may be

of lesser clinical importance compared with losses in patients with mild or moderate HL. Expert clinical opinion advises that CI implantation is not usually performed in patients with residual hearing.

Due to the lack of comparative evidence it is not possible to accurately compare the rates of adverse events between patients receiving the MEI or CI. Overall, there was some variability in outcomes between CI and MEI. However, in terms of absolute number and general severity, the safety issues between MEI and CI are similar both in terms of clinical and technical outcomes.

**Bone anchored hearing aid**

No comparative studies were available to inform on the safety of BAHA implantation. Seven case series with a total of 619 patients met the inclusion criteria for this report and were included. One study implanted the BAHA in adults only (Yuen et al 2009); and the six remaining studies included children in their population. Two studies included children exclusively (Davids et al 2007; Lloyd et al 2007). Although the included case series were retrospective, all enrolled patients consecutively. Patient populations tended to be larger in the BAHA studies than in the MEI studies, ranging from 34 (Yuen et al 2009) to 178 (Badran et al 2009).

Event rate has been reported in two manners, both of which may be at risk of bias (Table 31). The rate has been presented as a proportion of patients in the studies which specifically reported this outcome, which may be an over-inflated representation of the outcome, especially for rare events. The rate has also been presented as a proportion of the total patent number in all studies included for safety. This may be an under-representation of some outcomes, such as common outcomes which may not have been of interest in all studies (such as mild pain or infection).

**Mortality**

Only one study reported upon mortality (Gillett et al 2006). This study reported that one patient died, but did not provide any further details. It was unclear whether or not the death was due to BAHA implantation.

#### Table 31 Adverse events in 619 patients receiving BAHA implantation

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Outcome** | **Number of studies** | **Patient**  **N=** | **Incidence n=** | **Rate where reported (%)** | **Rate across total number of patients (%)** |
| BAHA loss | 1 | 85 | 8d | 9.4% | 1.29% |
| Traumatic fixture loss | 3 | 303 | 23 | 7.6% | 3.72% |
| Traumatic loss of osseointegration | 3 | 407 | 10a,b | 2.5% | 1.62% |
| Loss of osseointegration | 4 | 425 | 28a,c | 6.6% | 4.52% |
| Failed osseointegration | 1 | 85 | 6j | 7.1% | 0.97% |
| Extrusion | 1 | 21 | 0 | 0% | 0% |
| Skin growth over abutment | 4 | 347 | 55e | 14.3% | 8.89% |
| Loss of skin graft | 1 | 178 | 4f | 2.2% | 0.65% |
| Patient unsatisfied with gain | 2 | 229 | 3g | 1.3% | 0.48% |
| Infection | 5 | 491 | 39h | 7.9% | 6.3% |
| Intraoperative haemorrhage | 1 | 21 | 0 | 0% | 0% |
| Cerebrospinal fluid leakage | 1 | 21 | 0 | 0% | 0% |
| Hair growth over graft | 2 | 148 | 3i | 2% | 0.48% |
| BAHA use cessation for other reasons | 2 | 263 | 18k | 6.8% | 2.91% |
| Bony overgrowth | 2 | 263 | 14l | 6.8% | 2.26% |
| Pain in BAHA region | 1 | 178 | 7m | 3.9% | 1.13% |
| Incorrect placement of BAHA | 1 | 85 | 5n | 5.9% | 0.81% |
| BAHA revision (other reasons) | 1 | 85 | 1 (reason not documented) | 1.2% | 0.16% |
| Bleeding | 1 | 178 | 31o | 17.4% | 5.01% |
| Incision of the jugular vein | 1 | 178 | 1p | 0.6% | 0.16% |
| Dura exposed | 1 | 178 | 3q | 1.7% | 0.48% |

a: Four patients decided to abandon their BAHA and 27 requested revision

b: In one patient reosseointegration took place and the patient was wearing the implant at the time of follow-up, in two patients the abutment was tightened

c: One patient had a nontraumatic loss with multiple revisions (and also traumatic losses) and had a suspected bone disorder; three led to loss of implant

d: The mean age of children experiencing fixture loss was significantly less (7.8 years SD 4 years) compared with mean age in those without fixture loss (9.6 years SD 3.5 years) (*P*=0.05)

e: Generally managed patients with debridement and local wound care; one patient required minor flap revision; 13 had revision stage

II, one had BAHA resited, three had BAHA implanted in opposite ear, three awaiting revision, two no intervention

f: Three patients had partial failures (grafts healed within one month without further complications) and one patient had total necrosis of the skin flap (healed by primary intention). In one study children with split grafts from fixture site were less likely to develop hypertrophy of the graft than those with full thickness Wolfe grafts or split grafts taken from other areas (11 vs 36%, *P*<0.01) (Lloyd et al 2007)

g: Two couplings were removed but the fixtures left in place; one child realised he heard better with his original air conduction hearing aids

h: One patient had repeat infections around the implant site (conservative treatment and removal of the coupling was unsuccessful in providing infection resolution and consequently the implant was removed); 21 patients responded well to antibiotics, regular cleaning and Tri-Adcortyl ointment; three resulted in loose abutment; six resulted in abutment loss; three resulted in fixture loss; three resulted in contralateral BAHA; two patients were admitted to hospital for intravenous antibiotic treatment for severe infection of granulations

i: Electrolysis required in one patient; revision stage II required in two patients

j: All led to fixture loss; two failed osseointegration on the initial side (led to contralateral insertion of BAHA); one child never used the aid due to failed osseointegration

k: One child developed progressive SNHL which became unaidable with BAHA; one child played regular sport and found BAHA a hindrance; four abandoned by patient, 12 BAHAs removed

l: Six required revision stage II; four led to BAHA implantation in opposite ear; one awaiting intervention; one no intervention; two required removal by drilling

m: Four patients required removal of the abutment and flange fixture

n: BAHAs were implanted in an inappropriate position to allow auricular reconstruction or bone-anchored auricular prosthesis placement, and were all revised with contralateral insertion of BAHA

o: Three patients planned as day cases had to stay overnight because of bleeding; five patients had bleeding from the bone which was controlled using bone wax; 23 patients had recurrent bleeding around the abutment after 24 hours after operation

p: Sealed with a fibromuscular plug from the vastus lateralis and the operation was abandoned. The operation was subsequently completed with the placement of the fixture and the abutment somewhat more superiorly than usual

q: Did not lead to adverse events

**Damage to jugular vein**

One patient suffered damage to the jugular vein during BAHA implantation (Badran et al 2009). The incision was sealed with a fibromuscular plug and this operation was abandoned. A subsequent operation resulted in placement of the fixture and the abutment more superiorly than usual.

**Wound healing**

Two studies provided more extensive information on wound reactions, and classified these using the system described by Holgers et al (1988) (Badran et al

2009; Lloyd et al 2007). Briefly, the scale comprises 0=no irritation, 1=slight redness, 2=red and moist tissue, 3=red and moist with granulation tissue,

4=revision of skin penetration necessary (Lloyd et al 2008). In one study of children (n=85) 37 per cent had a score ≥2 at some stage, 91per cent of which had settled by the subsequent appointment (Lloyd et al 2007). Eighty per cent of children with thickening of graft required revision surgery. In the second study (n=178 implantations) 37 reactions took place within the first postoperative year (Badran et al 2009). Twenty six of these (70 per cent) were type 2 reactions which were managed with local ointments and oral antibiotics. A total of 11 type 3 reactions were reported. These were managed with either silver nitrate cautery to the granulations in five cases or granulation tissue excised under general

anaesthetic in six cases (followed by grafting in three cases). A total of three type 4 reactions were reported, all requiring temporary removal of the abutment. One of these patients subsequently abandoned their BAHA. Forty two patients had incomplete healing of the graft at the first follow-up visit, but no treatment was required (Badran et al 2009).

Generally, BAHA patients reported more wound healing difficulty than MEI patients. This is likely to be due to the skin grafts employed in BAHA implantation, as well as the additional maintenance care required for the BAHA’s abutment area.

**Children receiving BAHA**

Paediatric bone is softer than that of adults, and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage. Four studies reported specifically on fixture loss in children (Badran et al 2009; Davids et al 2007; Lloyd et al 2007; Tjellstrom et al 2007). In one study (n=178) 36 per cent of patients aged less than 16 had failed fixture, compared with 16 per cent of patients older than 16 (Badran et al 2009). Another study (n=40) reported five traumatic fixture losses in children and one failure of osseointegration (this child

suffered multiple revisions and traumatic losses, and was suspected to have a bone disorder) (Davids et al 2007). A third study (n=85) reported that 22 children experienced fixture loss (Lloyd et al 2007). The mean age of children experiencing fixture loss (7.8 years SD 4) was significantly less than the mean age in those without fixture loss (9.6 years SD 3.5) (*P*=0.05). Two children were reported to have had failed osseointegration. The final study (n=138) reported that of the two BAHAs lost, one was in a child and one was in an adult (Tjellstrom et al 2007).

Expert clinical opinion suggests that children may be less likely to perform adequate hygiene and maintenance of their BAHA site, which may cause fixture loss. Only two included studies reported upon skin reactions in children after BAHA implantation (Davids et al 2007; Lloyd et al 2007 as reported above).

Davids et al (2007) (n=40) reported that three children required skin revisions which were related to poor hygiene and less than adequate upkeep of the surgical site.

**Summary of safety for bone anchored hearing aid**

Seven case series with a total of 619 patients were used to inform on the absolute safety of the BAHA for hearing loss.

Owing to the surgical techniques used, the devices implanted and the sites of implantation, several adverse events which were reported in MEI implantation were not encountered in BAHA implantation, and vice versa. Examples of these included skin

and bony growth over the abutment (BAHA), and tinnitus and vertigo (MEI). However, other events may reasonably be expected to occur in either BAHA or MEI

implantation.

Expert clinical opinion suggests that some safety issues may be likely to occur more frequently in children, such as damage to the device or difficulties with osseointegration. The inclusion of children in the BAHA studies may have artificially inflated the

incidence of certain adverse events. Several studies included children yet did not report safety outcomes separately to those for adults.

The BAHA devices appeared to be more technologically consistent than the MEI, with no reported instances of BAHA device malfunction or failure compared with 0.9 per cent of all MEI devices implanted. Additionally, insufficient gain was more prevalent in MEI studies (1.6 per cent of all patients receiving MEI) than in BAHA studies (0.48 per cent of all patients receiving BAHA).

Once positioned, the MEI appeared to be more stable than the BAHA. Although 0.3 per cent of all MEIs migrated, loss of osseointegration or failed osseointegration was commonly encountered in the BAHA studies (4.52 per cent and 0.97 per cent respectively). The BAHA also appeared to be more susceptible than the MEI to damage or loss due to trauma. Device loss due to trauma was not encountered in the MEI studies yet 3.72 per cent of all implanted BAHAs were lost for this reason. Additionally, osseointegration was lost due to trauma in 1.62 per cent of all implanted BAHAs.

Expert clinical opinion suggests that paediatric bone is softer than that of adults, and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage.

Generally, BAHA patients reported more wound healing difficulty than MEI patients. This is likely to be due to the skin grafts employed in BAHA implantation, as well as the additional maintenance care required for the BAHA’s abutment area.

Due to the absence of comparative evidence it is not possible to accurately compare the rates of adverse events between patients receiving MEI or CI. In summary, it appears as if MEI is at least as safe as BAHA.

**Other safety considerations**

**Safety of MEI in MRI**

Two studies reported upon a total of three patients who underwent MRI after

VSB implantation (Schmuziger et al 2006; Todt et al 2004). In one case report two patients underwent MRI scanning with 1.5 T (Todt et al 2004). One patient experienced functional gain from the MEI, while the second patient did not due

to auditory neuropathy. The patient with functional gain described a loud, banging sound during the scanning procedure but did not report any vertigo, tinnitus, or related symptoms. After the MRI there were no changes in functional gain of this patient’s VSB. Neither patient experienced changes in the function of the external magnets at testing. MRI scanning did not visibly alter the fixation of the FMT clamp to the long process of the incus, and no fractures of the receiver’s bony bed on the skull surface were found in either patient. However one patient’s incus had some erosion on the surface of the long process where the MEI was attached.

A second case series reported upon one patient who underwent MRI (Schmuziger et al 2006). This patient’s VSB was dislocated after MRI, and revision surgery was necessary to reattach the transducer to the incus.

Communication with the manufacturer of the VSB device (Med-EL) indicates that this MEI is not MRI safe at any Tesla level. It can be removed if necessary (personal communication, 2009).

**Stability**

Patients may elect to use the MEI rather than the BAHA due to perceived stability in the event of head trauma. The BAHA was refused in one patient on the grounds that he was a rowdy boy, which was considered to heighten the risk of BAHA damage (Tringali et al 2008). This perception may be supported to an

extent as no losses of MEIs due to trauma were reported, compared with 3.72 per cent of all implanted BAHA devices. Additionally 1.62 per cent of all implanted BAHAs lost osseointegration due to trauma.

**Summary of safety**

No comparative evidence reporting on the safety of MEI compared with CI or BAHA was available. RCT evidence based on defined patient populations would better inform on any safety differences between MEI and the comparator procedures. In the absence of comparative safety data, information on the absolute safety of MEI, BAHA and CI implantation was included in this report. Even with the limitations in inclusion criteria for BAHA and CI data, much more evidence in terms of absolute patient numbers was available for CI. This reflects the fact that MEI is in its infancy compared with other more established alternatives.

Not all safety outcomes were uniformly reported across the identified studies. To address this, event rate has been reported in two manners throughout the report, both of which may be at risk of bias. The rate has been presented as a proportion of patients in the studies which specifically reported this outcome, which may be an over-inflated representation of the outcome, especially for rare events. The rate has also been presented as a proportion of the total patent number in all studies included for safety. This may be an under-representation of some outcomes, such as common outcomes which may not have been of interest in all studies (such as mild pain or infection).

Owing to the surgical techniques used, the devices implanted and the sites of implantation, several adverse events which were reported in BAHA or CI implantation were not encountered in MEI implantation. Several intracranial adverse events which were reported in CI patients were absent in MEI patients, including meningitis (which led to two deaths in children), dural damage and cerebrospinal fluid leak. The BAHA appeared to be more susceptible than the MEI to damage or loss due to trauma. Device loss due to trauma was not encountered in the MEI studies yet 3.72 per cent of all implanted BAHAs were lost for this reason, and osseointegration was lost due to

trauma in 1.62 per cent of all implanted BAHAs. Expert clinical opinion suggests that paediatric bone is softer than that of adults, and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage. Once positioned, the MEI appeared to be more stable than the BAHA. Although a small percentage of all MEIs migrated, loss of osseointegration or failed osseointegration was quite commonly encountered in the BAHA studies. Generally, BAHA patients reported more wound healing difficulty than MEI patients. This is likely to be due to the skin grafts employed in BAHA implantation, as well as the additional maintenance care required for the BAHA’s abutment area.

Conversely, several adverse were reported more frequently in MEI implantation than in BAHA or CI implantation. The incidence of tympanic membrane perforation was higher in MEI patients (0.7 per cent) than in CI patients (0.06 per cent), and was not reported for BAHA patients. Haematomae occurred more frequently in MEI patients (1.2 per cent) than in CI patients (0.02 per cent). Extrusions also occurred more frequently in MEI than in CI patients, and were not reported to have occurred in BAHA patients. Insufficient gain was more prevalent in MEI studies (1.6 per cent of all patients receiving MEI) than in BAHA studies (0.48 per cent of all patients receiving

BAHA). Insufficient gain was not reported in CI patients. The BAHA devices appeared to be the most technologically consistent of the three devices, with no reported instances of BAHA device malfunction or failure compared with 1.3 per cent of all CI devices and 0.9 per cent of all MEI devices implanted.

Residual hearing loss after implantation was an important adverse event which was uniquely reported in MEI patients. Expert clinical opinion advises that there is also a

significant risk of residual hearing loss in CI implantation, and that there is no risk of residual hearing loss in BAHA implantation. Residual hearing loss was reported upon by most MEI studies, with 13 studies reporting that patients suffered significant declines in mean residual hearing loss after MEI implantation. Unlike the CI literature, the MEI literature included many patients with mild or moderate HL. In these patients, any further deterioration in hearing may be of greater clinical importance compared with losses in patients with severe or profound HL. Patients with CHL did not report significantly worse residual hearing after implantation.

Expert clinical opinion endorsed by the Advisory Panel notes that certain adverse

events are likely to be more commonly seen in children than in adults. Paediatric bone is softer than that of adults, and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage. Additionally, children may be likely to sustain head trauma during rambunctious play. Children may also be less reliable at cleaning and maintaining their implant site. This may be especially important in the case of the BAHA.

Due to the differences in devices and the surgical procedures associated with them, the adverse events differ between MEI and its comparators. Overall, absolute evidence from case series studies suggests that MEI appears to be as safe as CI and BAHA.

### Is it effective?

Comparative effectiveness data have been presented according to the five PICO

populations identified in Table 4, Table 5 and Table 6 and listed below:

1. In patients with mild or moderate SNHL is the MEI more effective than the

BAHA?

2. In patients with severe SNHL is the MEI more effective than the CI?

3. In patients with mild or moderate MHL is the MEI more effective than the

BAHA?

4. In patients with severe MHL is the MEI more effective than the CI?

5. In patients with CHL is the MEI more effective than the BAHA? Additionally, one comparative study reported effectiveness outcomes for MEI

versus the CI in patients with SNHL of undefined severity (Verhaegen et al 2008). Due to the paucity of comparative studies identified, any effectiveness outcomes reported in this study have been included in this section.

An additional question has been included to inform on the effectiveness of MEI

versus external HAs.

**1. In patients with mild or moderate sensorineural hearing loss is the middle ear implant more effective than the bone anchored hearing aid?**

No comparative studies which assessed the effectiveness of the MEI versus the

BAHA in patients with mild or moderate SNHL were identified.

**2. In patients with severe sensorineural hearing loss is the middle ear implant more effective than the cochlear implant?**

No comparative studies which assessed the effectiveness of the MEI versus the

CI in patients with severe SNHL were identified.

**2a. In patients with sensorineural hearing loss of undefined severity is the middle ear implant as effective as the cochlear implant?**

One comparative study (NHMRC level III-3) assessed the effectiveness of the CI

versus the MEI in patients with SNHL of an undefined severity (Verhaegen et al

2008). A total of 10 patients used the Otologics MET and 123 patients used the CI, and patients were not reported to have been consecutively enrolled. All implants were performed unilaterally. MEI assessments were performed at least eight weeks postoperatively and CI assessments were conducted at one year follow-up to permit stabilisation of hearing; however, this retrospective study did not report upon losses to follow-up. The effectiveness outcomes were reported using projected data rather than actual measures.

**Quality of life and satisfaction measures**

This study did not report upon quality of life or satisfaction measures.

**Technical outcomes**

The study measured each patient’s maximum phoneme score (MPS) and used these to form a best fitted nonlinear regression line, representing the best score possible. The assessors then obtained each patient’s aided phoneme score in quiet at normal conversational level (65 dB sound pressure level). Comparisons were made for each hearing device’s relationship to the MPS line. In patients whose mean SNHL exceeded 85 dB HL this study found that 90 per cent of patients had better speech recognition scores with a CI than with the Otologics MET. The study also suggested that in patients with external otitis and whose mean SNHL was less than 85 dB HL, the PS65 score with the MEI was projected to be 42 per cent or less, while the PS65 score with the CI was projected to be greater than 42 per cent.

**Summary of the effectiveness of the middle ear implant vs the cochlear implant in patients with sensorineural hearing loss of undefined severity**

One comparative study was included (NHMRC level III). Ten included patients received MEI implantation, compared with 123 patients who received CI implantation. No quality of life or patient satisfaction measures were used to compare the effectiveness of the CI and the MEI. Only two technical effectiveness outcomes were reported as projected, and not actual, measures. For projected **speech recognition scores** in relation to the best score possible, 90 per cent of patients with severe hearing loss were likely to record better speech recognition scores with the CI than with the MEI. In patients with external otitis and whose mean SNHL was less than 85 dB HL, the **PS65 score** with the MEI was projected to be 42 per cent or less, while the PS65 score with the CI was projected to be greater than 42 per cent.

On the basis of this single study: regarding projected speech recognition in patients with severe hearing loss, MEI appears to be less effective than CI. Regarding projected PS65 score in patients with mild, moderate or severe hearing loss, MEI appears to be less effective than CI.

**3. In patients with mild or moderate mixed hearing loss is the middle ear implant more effective than the bone anchored hearing aid?**

No comparative studies which assessed the effectiveness of the MEI versus the

BAHA in patients with mild or moderate MHL were identified.

**4. In patients with severe mixed hearing loss is the middle ear implant more effective than the cochlear implant?**

No comparative studies which assessed the effectiveness of the MEI versus the

CI in patients with severe MHL were identified.

**5. In patients with conductive hearing loss is the middle ear implant more effective than the bone anchored hearing aid?**

No comparative studies which assessed the effectiveness of the MEI versus the

BAHA in patients with CHL were identified.

As only one comparative study was available to inform upon the relative effectiveness of the MEI compared with the BAHA and the CI, absolute effectiveness outcomes were collated for the MEI implantation alone. These outcomes were reported in level III and level IV studies. This information has been presented according to hearing loss indication and severity representative of the five populations: mild or moderate SNHL; severe SNHL; mild or moderate MHL; severe MHL; and CHL. Effectiveness outcomes which were reported in patients with SNHL or MHL of undefined severity have also been included and presented.

Importantly, few studies explicitly stated whether preoperative baseline measures were recorded with or without an external HA.

**1. Is the middle ear implant effective in patients with mild or moderate sensorineural hearing loss?**

A total of four studies, including two comparative studies and two case series, were used to assess the effectiveness of the MEI in patients with mild or moderate SNHL. It was not clearly stated whether baseline measures were measured with or without a HA.

**Comparative studies**

Two comparative studies (one NHMRC level III-2, one NHMRC level III-3) assessed the effectiveness of different types of MEI in 36 patients with mild or moderate SNHL (Snik and Cremers 2004a; Snik et al 2007). One study compared attachment types when implanting the VSB device (Snik and Cremers 2004a); while the second study compared the VSB and the Otologics MET in relation to baseline hearing (Snik et al 2007). Snik et al (2007) studied 23 patients and Snik and Cremers (2004a) studied 13 patients. Neither study reported whether or not these patients were consecutively enrolled. A total of three patients were lost to follow-up. Snik et al (2007) reported that one patient was excluded from analysis due to sudden symmetrical hearing deterioration after implantation, owing to hereditary diabetes. Snik and Cremers (2004a) reported that two patients were excluded from analysis: one due to chronic aeration problems which led to a chronic air-bone gap after surgery; and one due to pre-surgical hearing loss which exceeded the eligible range. While Snik et al (2007) stated that all patients had external otitis and were unable to successfully wear a conventional HA, it was not clearly stated whether or not baseline measures were unaided.

**Quality of life and satisfaction measures**

One study presented patient-reported outcomes in patients who received the VSB or the Otologics MET (Snik et al 2007). Quality of life was reported with the Glasgow Benefit Inventory (GBI), which is a standardised questionnaire utilised

to examine the impact of benefit derived from an otological treatment. GBI scores 12 months after implantation were comparable for the VSB and the Otologics MET. MEI implantation led to significant improvements on the overall benefit (32.9±15.4) (*P*<0.001) and the general scores (41.5±15.2) (*P*<0.001). Improvements were also noted on the social subscale (17.6±23.9) and the physical subscale (15.7±37.5). After implantation patients could hear well without pain and/or itching. The authors suggested that the relatively high mean GBI scores

may be due to the difficulties encountered by the patients when wearing any conventional HA, due to their external otitis.

**Technical outcomes**

*Abbreviated Profile of Hearing Aid Benefit (APHAB)*

One comparative study reported APHAB outcomes in patients with SNHL (Snik et al 2007). On average patients showed significant improvement in the Ease of Communication subscale after implantation (*P*<0.001). Other subscales also showed improvements (Table 32).

#### Table 32 Mean difference between pre- and post-implantation APHAB subscales

**APHAB Subscale**

**Difference after implantation (%)**

***P-*value**

EC 19.6 (9.0-30.1) <0.001

RV 12.7 (2.6-22.9) 0.02

BN 9.2 (1.3-17.2) 0.03

AV -2.5 (-12.7-7.7) ns

EC: ease of communication; RV: reverberation; BN: background noise; AV: aversiveness; ns: not significant

Individual patients with significant improvement or deterioration in the APHAB

subscales are summarised in Table 33.

#### Table 33 Individual differences between pre- and post-implantation APHAB subscales

**APHAB Subscale**

**Significant**

**Improvement n**

**Significant**

**Deterioration n**

EC 10 0

RV 9 1

BN 6 0

AV 1 1

Joint subscales 6 1 (EC, RV, BN)

EC: ease of communication; RV: reverberation; BN: background noise

There were no significant pre- to post-implantation differences between the VSB

and Otologics MET for all four subscales of the APHAB.

*Fitting and attachment*

The effectiveness of attaching the MEI by crimping alone was compared with crimping plus SerenoCem fixation (Snik and Cremers 2004a). Measured aided thresholds were subtracted from the target aided thresholds. At 2 kHz the group with crimping plus SerenoCem fixation was 10 dB better than the group with crimp fixation alone (*P*<0.05). No significant differences were reported at any other frequencies.

One study reported upon the adequacy of the audio processor fitting by comparing the mean functional gain of the MEI with the National Acoustic Laboratories (NAL) target gain (Snik et al 2007). The average difference between the measured gain and target gain was 2.3±6.4 dB (-11.5 to 7.6 dB), indicating that the audio processor fitting was adequate (Snik et al 2007).

In summary, comparative evidence from two studies suggests that there are no significant differences between different types of MEI device.

**Case series**

Two case series reported effectiveness outcomes of the MEI in 14 patients with mild or moderate SNHL (Barbara et al 2009; Foyt and Carfrae 2006). The case series had small patient numbers (Barbara et al 2009 n=6; Foyt and Carfrae 2006 n=9). Both were prospective studies and enrolled patients consecutively. Barbara et al (2009) did not report the length of follow-up or any losses to follow-up, while Foyt and Carfrae (2006) followed patients for 24 months and reported that one patient was lost to follow-up.

**Quality of life and satisfaction measures**

Neither study reported upon quality of life or satisfaction measures.

**Technical outcomes**

*Functional gain*

Both studies reported upon mean functional gain provided by the MEI (Table

34), and both found that gain was provided.

#### Table 34 Functional gain in patients with mild or moderate SNHL

|  |  |  |
| --- | --- | --- |
| **Study ID** | **N** | **Functional gain** |
| Barbara 2009 | 3 | Mean 15 dB (7-27)a |
| Foyt 2006 | 9 | Mean 13.9 (6-32) |

a: Estimated from figure, not stated in text

One study also reported upon mean aided thresholds when the MEI was turned

‘on’ and ‘off’ (Barbara et al 2009). One found that the mean gain provided in three patients when the MEI was turned ‘on’ as compared to ‘off’ was 55.7 dB (Barbara et al 2009).

**Summary of effectiveness of middle ear implant in patients with mild or moderate sensorineural hearing loss**

Four studies were available with a total of 50 patients. These included two comparative (level III-2 and level III-3) studies which reported on internal comparisons between different types of MEI and two case series (level IV). Outcome data were reported as before and after implantation. Quality of life and satisfaction measures were reported only in comparative studies. Outcomes were reported for 23 patients using the **GBI**. MEI implantation led to significant improvements on the overall benefit (*P*<0.001) and the general scores (*P*<0.001). However, the authors suggested that the relatively high mean GBI scores may be due to the difficulties encountered by the patients when wearing any conventional HA. It is possible that pre-fitting patients with a state-of-the- art, best-fit hearing aid may reduce this improvement.

Technical measures were reported for 23 patients by one comparative study. Patients showed a mean significant improvement in the **APHAB**’s Ease of Communication subscale after implantation (*P*<0.001). Individual significant improvements were noted in the Ease of Communication scale for 10 patients, in the Reverberation scale for nine patients, in the Background Noise for six patients and in the Aversiveness for one patient. Significant individual improvements were noted in the joint subscales (Ease of Communication, Reverberation, Background Noise) for six patients. However three patients reported a significant deterioration in APHAB subscales (one Reverberation, one Aversiveness, one joint subscales).

Technical measures were also reported for 12 patients in two case series. The **mean functional gain** was above 10 dB, which was defined as a clinically significant change (*P* value not provided). One study also reported that the mean gain provided when the MEI was turned ‘on’ and ‘off’ in three patients was 55.7 dB.

In summary, MEI appears to be effective in improving hearing from baseline, pre- implantation levels in patients with mild or moderate SNHL. However caution is needed in interpreting these results as they are drawn from evidence of four studies of variable quality and include data from a total of only 50 patients.

**2. Is the middle ear implant effective in patients with severe sensorineural hearing loss?**

One comparative study (level III-3) assessed the effectiveness of the MEI in 13 patients with severe SNHL (Snik et al 2004). This study compared the VSB and the Otologics MET MEIs. VSB patients had been using their device for more than a year, while the Otologics MET patients were first-time users and measurements were taken at least four months after device fitting. Snik et al

(2004) did not report whether or not patients were enrolled consecutively, and did not report on losses to follow-up. It was not clearly stated whether baseline measures were measured with or without a HA.

**Quality of life and satisfaction measures**

Snik et al (2004) did not report upon quality of life or satisfaction outcomes.

**Technical outcomes**

*Functional gain*

One study reported upon mean functional gain provided by the VSB and Otologics MET devices (Snik et al 2004). The gains provided by the devices were similar: VSB was 32.4 dB (63.8-75) and the Otologics MET 34 dB (70-82.5). The MET provided greater gain than the VSB in the frequencies up to 3000 Hz, while the VSB provided greater gain than the Otologics MET for frequencies higher than 3000 Hz.

This study also reported upon the adequacy of the audio processor fitting, by comparing the mean functional gain of the MEI with the National Acoustic Laboratories (NAL) target gain. The mean gain of the VSB exceeded the target gain by 29 dB (-4 to 11 dB), whereas the mean gain of the Otologics MET exceeded the target gains by 7 dB (-7 to 10 dB) (Snik et al 2004). No statistical analysis was performed on any outcome.

**Case series**

No case series reported upon patients who received the MEI for severe SNHL.

**Summary of effectiveness of middle ear implant in patients with severe sensorineural hearing loss**

Only one study, with a total of 13 patients, was available to assess the effectiveness of the MEI in patients with severe SNHL. This study was classified as an internal comparative study as it compared the effectiveness of the VSB and Otologics MET MEIs. As only one technical outcome was reported, this study has limited applicability.

No quality of life and patient satisfaction measures were reported upon. The **mean functional gain** provided by both the Otologics MET and the VSB devices exceeded

32 dB, which is considered to be clinically significant.

In summary, this single study suggests that MEI appears to be effective in improving hearing from baseline, pre-implantation levels in patients with severe SNHL. However, caution is needed in interpreting this result as it is drawn from a single, low-quality comparative study with only 13 patients.

**2a. Is the middle ear implant effective in patients with sensorineural hearing loss of undefined severity?**

Nine case series reported effectiveness outcomes in 262 patients receiving MEI

for SNHL of undefined severity (Fisch et al 2001; Garin et al 2002; Mosnier et al

2008; Snik and Cremers 1999; Snik et al 2006; Sterkers et al 2003; Zenner 2000; Zenner et al 2003; Zenner et al 2004). Two studies assessed the same cohort of patients over the short- and long-term (Mosnier et al 2008; Sterkers et al 2003). Eight studies provided effectiveness outcomes before and after MEI implantation, and five studies provided effectiveness outcomes with MEI ‘on’ and ‘off’ (Table

35). Where possible these sets of studies have been reported separately. Most studies reported that patients had tried and failed an external HA; however, no study explicitly stated whether preoperative, baseline measurements were conducted with or without a HA.

Patient numbers ranged from seven to 125. Two case series declared sponsorship issues – one study was supported by the manufacturer (Fisch et al 2001) and the second used devices which were supplied by the manufacturer (Snik and Cremers

1999). Eight of the nine case series were prospective, although only two enrolled patients consecutively (Garin et al 2002; Sterkers et al 2003). Follow-up ranged from two months to eight years, although most studies followed patients for less than 12 months.

#### Table 35 Case series for MEI for sensorineural hearing loss

**Study ID Before/After MEI MEI On/Off**

Fisch 2001 

Garin 2002 

Snik 1999  

Snik 2006 

Sterkers 2003  

*Same cohort reported in*

*Mosnier 2008*

Zenner 2000 

Zenner 2003  

Zenner 2004  

MEI: middle ear implant

**Quality of life and satisfaction measures**

A total of two level IV studies presented quality of life measures for 146 patients with SNHL of undefined severity (Snik et al 2006, Sterkers et al 2003). Both studies utilised the GBI. In addition Snik et al (2006) also presented data for the Short-Form Health Survey (SF-36) questionnaire and the Nijmegen Cochlear Implant Questionnaire (NCIQ). Meanwhile, Sterkers et al (2003) also employed a non-standardised questionnaire to measure perceived benefits from the implant.

*GBI*

GBI scores from these studies suggest that there was some substantial perceived benefit after implantation of the MEI. Sterkers et al (2003) reported that mean benefit scores demonstrated that the greatest benefit was noted for the general category in 89 per cent of SNHL patients (mean benefit score 20; estimated from

figure). There was no substantial benefit indicated for social support (55 per cent) and physical wellness (71 per cent). Notably, no statistical tests were presented to verify these results. Snik et al (2006) reported that SNHL patients perceived significant benefit after implantation as suggested by the mean overall GBI change of 33.9 (95% CI: 27.3 to 41.4; *P*<0.001).

*SF-36*

Snik et al (2006) reported that significant differences were noted in the physical and mental subcategories of the SF-36 questionnaire when comparing post- implantation and baseline outcomes (*P*=0.05 and *P*=0.01, respectively) (Table 36).

#### Table 36 SF-36 and NCIQ scores post-MEI implantation (Vibrant Soundbridge, Otologics MET)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Questionnaire** | **Baseline** | **After implantation** | **Individual change (95% CI)** | ***P-*value** |
| SF-36 physical | 0.512±0.087 | 0.479±0.100 | -0.033 (-0.063 to -0.002) | 0.05 |
| SF-36 mental | 0.488±0.099 | 0.534±0.071 | 0.046 (0.012 to -0.079) | 0.01 |
| NCIQ communication | 61.7±13.6 | 71.7±11.0 | 9.7 (3.8 to 13.5) | 0.002 |
| NCIQ psychological | 60.2±13.9 | 71.3±13.1 | 10.5 (2.8 to 18.2) | 0.01 |
| NCIQ social | 6302±15.9 | 76.0±12.4 | 13.6 (6.4 to 20.7) | 0.001 |

Mental functioning was the only underlying category with significantly improved scores after MEI implantation. Physical score actually decreased after implantation; this may be explained by the increase in subdomain bodily pain (*P*=0.05) consequent to surgery or the presence of the implant.

*NCIQ*

The communication-related physical, psychological and social subcategories of the NCIQ improved significantly after MEI implantation (Table 36; *P*<0.01 for all subdomains) (Snik et al 2006).

*Non-validated measures*

The non-standardised survey utilised by Sterkers et al (2003) indicated that 83 per cent of SNHL patients were satisfied or very satisfied with the MEI (VSB). A moderate correlation was noted between the ratings for global satisfaction with the ratings for sound quality and comprehension in noise (r=0.64). All other correlations were weak or non-existent. The survey noted that 50 per cent of respondents use the telephone with the MEI but no strong correlations on telephone use and other ratings were observed. A total of 76 per cent reported that they would repeat the procedure while 44 per cent indicated that they would consider binaural implantation (Sterkers et al 2003).

**Technical outcomes**

*Functional gain*

Two studies reported upon mean functional gain provided by the MEI (Table 37), and both found that approximately 26 dB of gain was provided. One further study reported upon gains for soft and moderate sounds (Snik and Cremers 1999). The gain provided by the MEI for soft sounds (averaged for the frequencies 500, 1500

and 4000 Hz) was 21 dB. In six of seven patients the gain of the MEI for moderate sounds was 17 dB.

#### Table 37 Functional gain in patients with SNHL of undefined severity

**Study ID N Functional gain**

Before/After

Sterkers 2003 125 Mean 26.7 dB

*Same cohort reported in Mosnier 2008*

On/Off

*Mean 26 dB (not significantly different from the 3-month outcomes)*

Garin 2002 9 Mean 25.8 dBa

a: Estimated from figure, not stated in text

One ‘before/after’ study also reported upon mean aided thresholds when the MEI was turned ‘on’ and ‘off’ and found that across 13 patients there was a median difference between MEI ‘on’ and ‘off’ of 13.2 dB (Zenner et al 2003).

One study reported upon loudness growth measurements taken before and after MEI implantation compared with target gain values (Snik and Cremers 1999). Results for low level sounds (40 dB SPL), sounds at a comfortable listening level (65 dB SPL) and loud sounds (90-95 dB SPL) were compared with target gain values calculated with the FIG6 method. Mean aided gain at 40 dB SPL was 21 dB, which on average was 8 dB (at 1.5 kHz) to 22 dB (at 0.5 kHz) lower than the

FIG6 target value (Snik and Cremers 1999). Mean aided gain at 65 dB SPL was 17 dB, which was 3-11 dB lower than the FIG6 target value. Mean aided gain at 90 dB SPL was within 5 dB of the FIG6 target values. No statistics were provided (Snik and Cremers 1999).

*Fitting*

One study reported upon the adequacy of the audio processor fitting (Snik et al

2006). This study compared the mean functional gain of the MEI with the National Acoustic Laboratories (NAL) target gain. The mean±SD difference between the measured gain and the target gain was 2.4±6.4 dB (-11.5 to 7.6 dB), suggesting that the audio processor fitting was adequate (Snik et al 2006).

*Speech recognition in quiet*

Two studies reported upon speech recognition when the MEI was switched ‘on’ and ‘off’ (Mosnier et al 2008; Zenner et al 2003). The first study assessed speech recognition in quiet, and found that when the MEI was switched ‘off’ the average word recognition score at 60, 80 and 90 dB was 52 per cent (+25%, -11%). When the MEI was switched ‘on’ the word recognition score was significantly improved to 87 per cent (+6%, -15%) (*P* value not provided) (Zenner et al 2003).

In the second study 27 of 125 patients were assessed at three months and at five to eight years post surgery for speech comprehension with the MEI ‘on’ and ‘off’. No details were given regarding the selection of these patients (Mosnier et al

2008). Both the ‘on’ and ‘off’ speech comprehension scores significantly deteriorated from three months post surgery to five to eight years post surgery. The average decrease in speech comprehension score at five to eight years compared with three months post surgery was 19.4 per cent for VSB ‘off’ and 8.2 per cent for VSB ‘on’ (Mosnier et al 2008). Patients’ hearing also worsened

between these periods. From initial to final follow-up, the mean hearing present when the MEI was switched ‘off’ deteriorated from 56±6.5 per cent to 37±7.1 per cent (*P*<0.01). Similarly, the mean hearing present when the MEI was

switched ‘on’ deteriorated from 89±4 per cent to 81±5.3 per cent (*P*<0.05). When MEI was switched ‘on’ the deterioration present was less pronounced than that at MEI ‘off’, signifying an effect from the MEI.

*Speech discrimination in noise*

Three studies reported upon speech discrimination in noise after MEI implantation (Garin et al 2002; Zenner 2000; Zenner et al 2003). One study provided ‘on/off’ measures, but did not clearly specify whether the MEI ‘unaided’ condition was preoperative or postoperative (Garin et al 2002). In this study at a signal-to-noise ratio of 0 dB (equivalent speech and noise signal intensities) MEI

‘on’ achieved higher scores than MEI ‘off’ (85±20 and 55±40 per cent respectively). A cohort of 15 normal listeners achieved 95 per cent. At signal-to- noise ratio of -5 dB (noise was increased by 5 dB), MEI ‘on’ achieved higher scores than MEI ‘off’ (60±28 and 29±31 per cent respectively). Normal listeners achieved 75 per cent (Garin et al 2002). At signal-to-noise ratio of -10 dB, MEI

‘on’ achieved higher scores than MEI ‘off’ (31±25 and 7±17 per cent respectively). Normal listeners achieved 45 per cent. Overall MEI ‘on’ improved hearing in noise compared with the MEI ‘off’, although no statistical results were provided. The MEI ‘on’ did not provide hearing equivalent to that of normal listeners (Garin et al 2002). This study also provided effectiveness outcomes using an unvalidated measure for in-noise assessment (Garin and Galle test). At S/N= -

5dB, the percentage of words correctly understood in background noise was VSB

‘off’ 8 per cent ±13 and VSB ‘on’ 34 per cent ±18 (no statistical analysis provided). Normal listeners (n=15) achieved 95 per cent. At S/N= -10 dB, the percentage of words correctly understood in background noise was VSB ‘off’ 66 per cent ±22 and VSB ‘on’ 98 per cent ±4 (no statistical analysis provided). Normal listeners achieved 100 per cent.

The other two studies reported ‘before/after’ measures (Zenner 2000; Zenner et al 2003). One reported that the sentence recognition threshold (a score of 50% correct) was in the range -2 to +1 dB signal-to-noise ratio (Zenner 2000). After MEI implantation the articulation index improved by 105 per cent and auditory localisation was correct 89.5 per cent of the time. The second study found that 11 patients (84.6 per cent) reached the sentence recognition threshold in the range -2 to +1 dB signal-to-noise ratio (Zenner et al 2003). When noise was directed towards the contralateral unaided, preoperative ear (thus allowing the implanted ear to focus on the speech signal), sentence recognition was 86 per cent (interquartile range +10%, -13%). This was significantly better than the sentence recognition of the unaided ear 77 per cent ±11 (median value with interquartiles) (*P* value not provided) (Zenner et al 2003).

*Speech discrimination in quiet*

Three studies reported upon ‘before/after’ outcomes for speech discrimination in quiet (Snik and Cremers 1999; Zenner 2000; Zenner et al 2003). In the first study standard word lists consisting of monosyllables were used, with the speech gain being the shift in dB between the aided score and the unaided score at 65 dB. A mean speech gain of 20 dB (13-28) was observed across the seven patients (Snik and Cremers 1999). In the second study preoperatively 11/13 patients (84.6 per

cent) had a median loss of 20 per cent (interquartile range +5%, -5%) (Zenner et al 2003). With the MEI all patients attained 100 per cent word recognition. This study also reported upon sentence recognition. Twelve patients (92.3 per cent) achieved a score of 100 per cent after implantation, and the remaining patient achieved 98 per cent. The median value of sentence recognition in quiet at 65 dB SPL was 100 per cent (Zenner et al 2003). The third study reported that discrimination was significantly improved in 18 of 20 patients (90 per cent) after MEI implantation (statistics not provided) (Zenner 2000). Discrimination reached

100 per cent in 14 patients compared with four patients preoperatively. Additionally 100 per cent of standardised sentences were understood by 15 patients (75 per cent).

**Summary of effectiveness of middle ear implant in patients with sensorineural hearing loss of undefined severity**

All studies for this indication were case series (nine studies with a total of 262 patients). Statistical analyses were rarely provided to substantiate effectiveness outcomes.

Several quality of life and satisfaction measures were reported upon. Two studies reported upon validated quality of life measures in a total of 146 patients. One study (n=21) reported that patients perceived significant benefit in **GBI** score after MEI implantation (*P*<0.001). This study also reported significant improvements in the mental subcategory of the **SF-36** questionnaire when comparing baseline and post- implantation outcomes (*P*=0.01). The physical score decreased significantly after implantation (*P*=0.05), possibly due to the presence of the implant. This study also reported that the communication-related subcategories of the **NCIQ** improved significantly after MEI implantation (*P*≤0.01)

Several technical measures were also reported. **Mean functional gain** was reported for a total of 134 patients. MEI implantation provided at least 25 dB mean functional gain. Improvements of >10 dB are considered to be a clinically significant improvement. Speech recognition in quiet was reported by two case series. In all cases outcomes were improved in after MEI implantation or with MEI ‘on’. No statistical reporting was provided. One study selectively reported upon 27 of 125 patients, and found that both MEI ‘on’ and MEI ‘off’ speech discrimination scores significantly worsened from three months post surgery to five to eight years postsurgery (MEI ‘off’ *P*<0.01; MEI ‘on’ *P*<0.05).

**Speech discrimination in quiet** was reported upon by three case series. One study (n=7) noted a mean speech gain of 20 dB (13-28) after MEI implantation. The second study found that the median value of sentence recognition in quiet at 65 dB SPL was

100 per cent. The third study reported that discrimination was significantly improved in

18 of 20 patients (90 per cent) after MEI implantation. However, no study provided statistical analysis.

In summary, MEI appears to improve hearing in patients with SNHL of undefined severity. However, caution is needed in interpreting these results as the data are of relatively low quality and outcome measures are variable between studies.

**3. Is the middle ear implant effective in patients with mild or moderate mixed hearing loss?**

No comparative studies assessed the effectiveness of the MEI in patients with

mild or moderate MHL. Six case series reported effectiveness outcomes for a total of 47 procedures in 46 patients with moderate MHL (Cuda et al 2009; Dumon et

al 2009; Foyt and Carfrae 2006; Lefebvre et al 2009; Suzuki et al 1989; Yanagihara et al 1997). In two case series the MEI was modified in some manner (Cuda et al

2009; Lefebvre et al 2009). In one case series the MEI’s titanium attachment clip was cut off to permit implantation on the round window, which was necessary as middle ear anatomy varied due to the conductive component of the hearing loss (Cuda et al 2009). In the second case series a modified total ossicular replacement prosthesis (TORP) was clipped to the end of the MEI’s transducer (Lefebvre et al

2009).

None of the six case series explicitly stated that preoperative baselines were obtained without the use of an external HA. Only one patient was reported to be unable to tolerate a traditional HA (Foyt and Carfrae 2006).

Patient numbers were very small and ranged from one to 13. One case series was authored by employees of the MEI manufacturer (Lefebvre et al 2009). All six of the case series were prospective, although only one study enrolled patients consecutively (Foyt and Carfrae 2006). Where reported, follow-up ranged from six months to 54 months (Cuda et al 2009; Dumon et al 2009; Foyt and Carfrae 2006; Lefebvre et al 2009; Yanagihara et al 1997).

**Quality of life and satisfaction measures**

None of the case series reported quality of life or satisfaction outcomes.

**Technical outcomes**

*Functional gain*

Four studies reported upon functional gain provided by the MEI (Table 38). A mean functional gain was conferred by the MEI in all studies and ranged from approximately 26 dB to 32 dB (Table 38).

#### Table 38 Mean functional gain of the MEI in patients with mild or moderate mixed hearing loss

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study ID** | **N** | **Frequencies used** | **Unaided, preoperative threshold (mean)** | **Aided threshold**  **(mean)** | **Functional gain (mean)** |
| Cuda 2009 | 8 | 500 Hz to 4000  Hz | 62.8 dB HL | 32.2 dB HL | 30.6 dB |
| Dumon 2009 | 13 | 500 Hz to 4000  Hz | 66 dB HL | 34 dB HL | 32 dB |
| Lefebvre 2009 | 6 | 250 Hz to 3000  Hz | 63 dB HLa | 37.5 dB HL | 26.17 [SD 5.15] dB, decreased to 20.83 [SD  6.22] dB at 12 months |
| Yanagihara  1997 | 9 | - | 67.1 dB HL | 36.5 dB HL | 30.6 dB |

a: Data approximated from figures

dB: decibels; HL: hearing level; SD: standard deviation; SPL: sound pressure level; - indicates not reported

One further study reported very briefly upon effectiveness outcomes (Suzuki et al

1989). Hearing was reported to have improved in all implanted cases, but no further data was supplied. This study reported no further effectiveness outcomes, aside from the fact that 7/9 patients (77.8 per cent) use their MEI all the time.

*APHAB*

One study reported APHAB outcomes after MEI implantation in six patients with MHL (Lefebvre et al 2009). APHAB scores were provided for five of six individual patients. After MEI implantation significant improvements were shown in the Ease of Communication (32.8 per cent), Reverberation (11 per cent) and Background Noise (13.6 per cent) scales. A mean worsening of approximately

17.6 per cent was found on the Aversiveness scale (data approximated from figures). This study was unclear as to whether the MEI-aided condition was compared to an unaided or to a HA pre-surgical condition.

*Speech reception threshold*

One study reported upon speech reception threshold (SRT) in quiet (Dumon et al

2009). This study calculated SRT for both 50 per cent and 100 per cent intelligibility and reported improvements in SRT in quiet after activation of the MEI (Table 39).

#### Table 39 SRT in quiet in patients with mild or moderate mixed hearing loss

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study ID** | **Preoperative** | **MEI off** | **MEI on** | **Difference** |
| Dumon 2009 | 77 dBa | 75 dBa | 52 dBa | Post-op: 2 dBa  Total: 25 dBa |
|  | 89 dBb | 83 dBb | 59 dBb | Post-op: 6 dBb  Total: 24 dBb |

a SRT intelligibility of 50%

b SRT intelligibility of 100%

dB: decibels; HL: hearing loss; MEI: middle ear implant; SPL: sound pressure level; - indicates not reported

Speech perception at conversational levels was reported upon by two studies (Cuda et al

2009; Lefebvre et al 2009). Both studies indicated an improvement in speech perception after MEI implantation (Table 40).

#### Table 40 Speech perception at conversational level

|  |  |  |  |
| --- | --- | --- | --- |
| **Study ID** | **Preoperative** | **Postoperative** | **Difference** |
| Cuda 2009a  Lefebvre 2009 | -  - | 88.3% [SD 14.6] (range 65-100%)  36.25% [SD 46.07] | -  63.33% [SD 32.04] (range 10-90) |

a Measured at 60 dB

SD: standard deviation; - indicates not reported

**Summary of effectiveness of middle ear implant in patients with mild or moderate mixed hearing loss**

No comparative studies were available to inform on the effectiveness of MEI in patients with mild or moderate MHL. Six case series which assessed a total of 47 procedures in

46 patients were utilised for effectiveness outcomes. These NHMRC level IV studies had very small patient numbers, and each failed to provide statistical analysis to substantiate effectiveness outcomes. Two of the case series modified the MEI devices due to varied middle ear anatomy.

No quality of life or patient satisfaction measures were provided. Four technical effectiveness outcomes were reported upon. Four case series found that a mean **functional gain** was provided by the MEI, and ranged from approximately 26 dB to approximately 32 dB. Improvements of >10 dB are considered to be clinically significant. **APHAB** outcomes were reported for five of six included patients in one study, although no statistical analysis was provided. Significant improvements were reported to have occurred after MEI implantation in the Ease of Communication, Reverberation and Background Noise scales. **Speech reception threshold** outcomes were reported for a total of 13 patients. Improvements were noted after activation of the MEI for both 50 per cent (25 dB) and 100 per cent (24 dB) intelligibility, although no statistical analysis was provided. **Speech perception at conversational level** was

reported separately in 14 patients. Improvements were reported after MEI implantation. Speech perception outcomes were reported by three studies.

In summary, in these case series, MEI implantation or activation generally led to improvements in patients with mild or moderate MHL. However caution is needed in interpreting these results as they are drawn from a small number of low quality case series including only 46 patients and no statistical analyses were reported.

**4. Is the middle ear implant effective in patients with severe mixed hearing loss?**

Two case series reported effectiveness outcomes in 47 patients who received MEI for severe MHL (Colletti et al 2006; Streitberger et al 2009). Both case series reported ‘before/after’ effectiveness outcomes, and one also reported additional

‘on/off’ outcomes (Colletti et al 2006). One case series reported that the MEI was modified by cutting off its titanium clip before positioning the device on the

round window (Streitberger et al 2009). This placement was due to varied middle ear anatomy.

One case series reported upon seven patients (Colletti et al 2006) and the second reported upon 40 patients (Streitberger et al 2009). Both case series were prospective, although neither was reported to have enrolled patients consecutively. Follow-up ranged from six to nine months. Neither case series explicitly stated that preoperative baselines were measured without the use of an external HA.

**Quality of life and satisfaction measures**

None of the case series reported quality of life or satisfaction outcomes.

**Technical outcomes**

*Functional gain*

Both studies reported upon functional gain provided by the MEI. A mean functional gain was conferred by the MEI in both studies (Table 41).

#### Table 41 Mean functional gain of the MEI in patients with mixed hearing loss

| **Study Ib** | **N** | **Frequencies used** | **Preoperative threshold**  **(mean)** | **Aided threshold (mean)** | **Functional gain (mean)** |
| --- | --- | --- | --- | --- | --- |
| Colletti 2006 | 7 | 250Hz to 4000Hz | 72.9 dB HL | 23.6dB HL | 49.3 dB |
| Streitberger 2009 | 40 | 250Hz to 4000Hz | 82.38 dB SPL [SD 2.33] | 50.63 dB SPL [SD 5.81] | 31.75 dB at activation |
| - | - | - | - | 47.89 dB SPL [SD 13.76] at 6-9 month follow-up | 34.5 dB at 6-9 month follow-up |

dB: decibels; HL: hearing level; SD: standard deviation; SPL: sound pressure level; - indicates not reported

One case series also compared the effectiveness of the MEI when set to either

‘on’ or ‘off’ (Colletti et al 2006). The mean MEI ‘off’ threshold across 500-4000

Hz was 79.5 dB HL, which improved to 23.6 dB HL after the MEI was turned

‘on’ (data approximated from figures, no statistical comparison provided) (Colletti et al 2006). This improvement brought patients into the mild hearing loss category (20-39 dB HL, see Table 1). However the placement of the MEI caused a worsening in AC thresholds from approximately 72.9 dB HL to approximately

79.5 dB HL in the seven patients. This effect was attributed to inadequate coupling of the bone vibrator, presumably due to oedema, at the time of postoperative measurements.

Both studies compared aided thresholds at short-term follow-up and longer-term follow-up (Colletti et al 2006; Streitberger et al 2009). None of these studies found a significant difference between aided thresholds at short term (nine months in

Colletti et al 2006; three months in Streitberger et al 2009) and longer term (12 months in Colletti et al 2006; six to nine months in Streitberger et al 2009), suggesting that the placement and efficiency of the MEI was stable in these 47 patients.

*Speech reception threshold*

Both case series reported upon SRT in quiet. One study calculated SRT for only

50 per cent intelligibility (Colletti et al 2006) and the second study did not report the intelligibility levels of SRT calculations (Streitberger et al 2009) and the evaluators conservatively assumed that these were 50 per cent. Both studies reported improvements in SRT in quiet after activation of the MEI (Table 42). In one cohort the SRT improved further between activation (62.82 dB SPL; 32.6 dB gain) and long-term follow-up (53.33 dB SPL; 40.95 dB gain) (Streitberger et al

2009). Additionally, one study reported that while only one patient was able to achieve 100 per cent intelligibility preoperatively, six of seven patients achieved

100 per cent postoperatively (Colletti et al 2006).

#### Table 42 SRT in quiet in patients with mixed hearing loss

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study ID** | **Preoperative** | **MEI off** | **MEI on** | **Difference** |
| Colletti 2006 | 85 dB HL (range  70-100)a | - | 50 dB HL (range  30-70)a | *P*<0.001 |
| Streitberger 2009 | - | 94.28 dB SPL | 53.33 dB SPL | 40.95 dB gain |

a SRT intelligibility of 50%

dB: decibels; HL: hearing loss; MEI: middle ear implant; SPL: sound pressure level; - indicates not reported

Speech perception at conversational levels was reported upon by one study, which indicated an improvement in speech perception after MEI implantation (Streitberger et al 2009) (Table 43). The SRT improved further between activation (91.15 per cent) and long-term follow-up (95.75 per cent) (Streitberger et al 2009).

#### Table 43 Speech perception at conversational level

|  |  |  |
| --- | --- | --- |
| **Study ID Preoperative** | **Postoperative** | **Difference** |
| Streitberger 2009 47.75% [SD 30.51] | 95.75% [SD 7.81] | 48% |

SD: standard deviation; - indicates not reported

**Summary of effectiveness of middle ear implant in patients with severe mixed hearing loss**

No comparative studies were available to inform on the effectiveness of MEI in patients with mild or moderate MHL. Two case series (NHMRC level IV) which assessed a total of 47 patients were utilised for effectiveness outcomes. One case series modified the MEI devices due to varied middle ear anatomy.

No quality of life or patient satisfaction measures were reported upon, and only three technical outcomes were reported on. Mean functional gain afforded by the MEI ranged from 49.3 dB to 34.5 dB. In seven patients **speech reception threshold in quiet** improved significantly from preoperative to MEI ‘on’ (*P*<0.001). In 40 patients a 40.95 dB gain was noted between MEI ‘off’ and MEI ‘on’, although no statistical analysis was provided. One study reporting upon **speech perception at conversational levels** in 40 patients found a 48 per cent improvement from mean preoperative level to mean postoperative level, although no statistical analysis was provided.

In summary, in these case series, MEI implantation or activation generally led to improvements in patients with severe MHL. However caution is needed in interpreting these results as they were drawn from a small number of low quality case series including only 47 patients and with limited reporting of statistical analyses.

**4a. Is the middle ear implant effective in patients with mixed hearing loss of an undefined severity?**

No comparative studies reported upon the effectiveness of the MEI in patients with MHL of an undefined severity. One case series reported effectiveness outcomes in 19 patients who received MEI for MHL which ranged in severity from moderate to severe (Colletti et al 2009). This study was methodologically designed to be a comparative study but the comparator (total ossicular replacement prosthesis) was not a comparator of interest for this report. For the purposes of this report the single arm that assessed MEI in this study has been included as level IV evidence. The MEI was modified by cutting off the titanium attachment clip. This permitted implantation on the round window which was necessary as middle ear anatomy varied due to the conductive component of the hearing loss.

Although this case series was prospective, the 19 patients were not reported to have been enrolled consecutively. Mean follow-up was 36 months and Colletti et al (2009) did not report upon losses to follow-up. It was not explicitly stated whether or not preoperative baseline measures were recorded with or without an external HA.

**Quality of life and satisfaction measures**

Colletti et al (2009) did not report upon quality of life or satisfaction outcomes.

**Technical outcomes**

*Functional gain*

Colletti et al (2009) found that a mean functional gain of 58.31 dB [SD 38.6] was conferred by the MEI. Gains higher than 10 dB were obtained in 14/19 (73.7 per

cent) patients.

*Speech perception at conversational level*

Speech perception at conversational levels significantly improved after MEI

implantation (Table 44).

#### Table 44 Speech perception at conversational level

|  |  |  |  |
| --- | --- | --- | --- |
| **Study ID** | **Preoperative** | **Postoperative** | **Difference** |
| Colletti 2009a | 6.8%; [SD 2.5] | 86.2%; [SD 36.5] | *P*=0.0004 |

a Measured at 65 dB

SD: standard deviation; - indicates not reported

**Summary of effectiveness of middle ear implant in patients with mixed hearing loss of undefined severity**

No comparative studies were available to inform on the effectiveness of MEI in patients with MHL of undefined severity. One case series (NHMRC level IV) which assessed a total of 19 patients was utilised for effectiveness outcomes. This case series modified

the MEI devices due to varied middle ear anatomy.

No quality of life or patient satisfaction measures were reported, and only two technical measures were reported. The **mean functional gain** provided by the MEI was 58.31 dB [SD 38.6]. The **speech perception at conversational levels** was significantly improved from preoperative to after MEI implantation (*P=*0.0004).

In summary, generally MEI implantation led to improvements in patients with MHL of undefined severity. However caution is needed in interpreting these results as they are drawn from a single case series involving only 19 patients.

**5. Is the middle ear implant effective in patients with conductive hearing loss?**

No comparative studies assessed the effectiveness of the MEI in patients with CHL. Two case series reported effectiveness outcomes in a total of 12 patients who received MEI for CHL (Frenzel et al 2009; Siegert et al 2007) (Table 15). These case series assessed ‘before/after’ effectiveness outcomes in patients with either unilateral osseous atresia (n=7) or congenital auricular atresia (n=5, four of which had unilateral and one of which had bilateral malformations). In one case series all seven patients had moderate CHL (Frenzel et al 2009) while in the second patients were reported to have moderate to severe CHL (Siegert et al

2007). In one case series the titanium clip of the MEI was removed and the circular base was placed into the round window niche (Frenzel et al 2009). These seven patients all received VSB implantation integrated in a total auricular reconstruction. In the second study the coupling device was modified and a titanium prosthesis designed especially for the study was used for sound transmission (Siegert et al 2007).

Both case series were prospective, although only one reported that patients were enrolled consecutively (Frenzel et al 2009). Mean follow-up ranged from three to eight months and neither case series reported upon losses to follow-up. Neither case series explicitly stated whether preoperative baseline measures were recorded with or without an external HA. In one case series the MEIs were supplied without charge by the manufacturer, and one author was an employee of the manufacturer (Siegert et al 2007).

**Quality of life and satisfaction measures**

Neither of the case series reported quality of life or satisfaction outcomes.

**Technical outcomes**

*Functional gain*

Both studies reported upon mean functional gain across four frequencies provided by the MEI, which was measured at 45.5 dB (Frenzel et al 2009) and 36 dB HL (Siegert et al 2007).

One study reported that the mean aided threshold was 23.8 dB HL [SD 6.2]

across four frequencies and 23.5 dB HL [SD 5.8] across eight frequencies (Frenzel et al 2009). Both of these thresholds were 13.3 dB worse than the BC threshold; however, this gain allowed the seven patients to be re-classified from the higher end of the moderate category (preoperatively 69.2 dB HL) to the lower end of the mild hearing loss category (23.8 dB HL) (Frenzel et al 2009).

*Speech reception threshold*

In one study the mean speech reception threshold (50% speech discrimination) improved from 59 dB in the unaided condition to 21 dB with the MEI on, representing a 38 dB functional gain for speech (Frenzel et al 2009). In the second study the average speech threshold showed a gain after implantation of 32 dB HL (Siegert et al 2007).

*Speech discrimination*

Both studies reported upon speech discrimination at the average conversational level. In one study speech discrimination improved by 70 per cent (no further data provided) (Siegert et al 2007), and in the other study improved from 76 per cent preoperatively to 99 per cent with the MEI activated, representing a 75.7 per cent improvement (Frenzel et al 2009). One study provided further speech discrimination results (Frenzel et al 2009). At 50 dB speech discrimination with

the MEI on was 64 per cent [SD 18.4], compared with 0 per cent preoperatively. At 80 dB speech discrimination with the MEI on was 100 per cent [SD 0], compared with 94 per cent preoperatively (data estimated from figures).

One study reported upon mean speech discrimination in noise (Frenzel et al

2009). The mean speech discrimination score in noise with the MEI on was 75 per cent at 60 dB and 97 per cent at 80 dB.

**Summary of effectiveness of middle ear implant in patients with conductive hearing loss**

No comparative studies assessed the effectiveness of the MEI in patients with CHL. Two case series reported effectiveness outcomes in a total of 12 patients who suffered from either unilateral osseous atresia or congenital auricular atresia. The implanted MEIs were modified to permit placement due to anatomic variation.

No quality of life or patient satisfaction measures were reported. Several technical outcomes were reported. The **mean functional gain** in the 12 patients exceeded 36 dB HL. A change of 10 dB HL or greater is considered to be clinically significant. After MEI implantation in seven patients, the **mean aided thresholds** were worse than the BC threshold. However, the gain provided by the MEI allowed the patients to be re- classified from the higher end of the moderate category to the lower end of the mild hearing loss category. Mean **speech reception threshold** improved by at least 32 dB HL after MEI implantation, although no statistical analyses were provided. **Speech discrimination in quiet** was improved by 70 per cent in one case series and by 75.7

per cent in the second, although no statistical analyses were provided.

In summary, although these 12 patients appeared to benefit from MEI implantation, this evidence is limited by the small number of patients studied and lack of statistical analysis. Additionally, these patients all suffered either unilateral osseous atresia or congenital auricular atresia, and it is unclear whether the benefits seen in these patients would extend to patients with other types of CHL.

**Effectiveness of the middle ear implant versus the external hearing aid**

A total of 20 comparative studies with a total of 763 patients were identified which assessed the effectiveness of the MEI compared with the HA for SNHL (Table 17; Table 20) and MHL (Table 18). Two studies reported upon the same cohort of patients with MHL (Caye-Thomasen et al 2002; Tos et al 1994). One study was a regulatory document prepared for the US Food and Drug Administration (FDA) (Symphonix Devices, Incorporated 2000). As this study was authored by an MEI manufacturer and has not been published in a peer- reviewed journal, outcomes have been reported separately from the remaining comparative studies.

Four studies reported that patients used optimally fitted, best fit or state-of-the-art

HA for comparison with the MEI (Chen et al 2004; Todt et al 2002; Uziel et al

2003; Verhaegen et al 2008). Where reported, the remaining studies used the patient’s own conventional HA. One study stated that the HA used were not the best possible digital HA due to the high cost of these devices (Thill et al 2002).

**Effectiveness of the middle ear implant versus the external hearing aid:**

**sensorineural hearing loss**

A total of 14 comparative studies were identified which assessed the effectiveness of the MEI compared with the HA for SNHL (Table 17). These studies included

a total of 664 patients.

Several studies appeared to have been supported in some manner by MEI device manufacturers (Chen et al 2004; Fraysse et al 2001; Hough et al 2001; Jenkins et al

2007; Matthews 2002; Snik and Cremers 2001; Thill et al 2002). Five studies enrolled patients consecutively (Fraysse et al 2001; Hough et al 2001; Luetje et al

2002; Matthews 2002; Uziel et al 2003) and the remaining studies did not report upon enrolment. The sample sizes ranged from five to 282, although approximately half of the studies recruited less than 20 patients each (Chen et al

2004; Hough et al 2001; Snik and Cremers 2001; Thill et al 2002; Todt et al 2002; Uziel et al 2003). Where reported, the length of follow-up ranged from two to 18 months. While all studies provided inclusion criteria, four studies failed to provide exclusion criteria (Roland et al 2001; Thill et al 2002; Todt et al 2002; Uziel et al

2003).

**Quality of life and satisfaction measures**

Six comparative studies reported results on quality of life and/or satisfaction after MEI implantation in patients with SNHL. Most studies utilised general subjective statements to reflect patient satisfaction (Jenkins et al 2007; Roland et al 2001; Snik and Cremers 2001; Todt et al 2005). Two studies utilised the Hearing Device Satisfaction Score (HDSS)1 to assess patients hearing difficulties in various listening situations (Thill et al 2002; Uziel et al 2003). No statistical tests were presented for quality of life or satisfaction measures after MEI implantation.

1 Developed by Symphonix Devices.

*HDSS*

Thill et al (2002) reported that there was an average improvement of satisfaction for all subcategories of the HDSS scale (canal occlusion, sound quality, phoning, usefulness, quality of life and Lersen effect) (data not provided). All patients were wearing their VBS every day and all day long, a substantial improvement to their hearing aids (Thill et al 2002). Similarly, Uziel et al (2003) stated that most patients (5/6) experienced significant improvement in satisfaction ratings for most subcategories (sound quality, feedback, quality of life, ease of use) (*P*=0.038 to

0.043), except for mould issues and telephone use.

*General and unvalidated*

Four SNHL studies that presented general patient satisfaction statements reported positive outcomes post implantation (Jenkins et al 2007; Roland et al 2001; Snik and Cremers 2001; Todt et al 2005). One study noted that 85 per cent (17/20) of patients utilised the VSB every day (Jenkins et al 2007) and most used it for longer than 11 hours per day. Another study reported that 80 per cent (4/5) of patients used the VSB all day (Snik and Cremers 2001).

The results infer that patient satisfaction for the VSB were generally positive across these studies. Todt et al (2005) stated that most patients were highly satisfied (but wanted higher technical flexibility of the audio processor). The proportion of patients who would consider binaural MEI implantation was reported to be 80 per cent (Todt et al 2005).

For the SOUNDTEC MEI, one study demonstrated that patient satisfaction was approximately 32.6 per cent higher compared to optimally fit traditional hearing aids (actual data not reported). In addition, 95.6 per cent of patients noted overall preference for the SOUNDTEC system over the optimally fit traditional hearing aid (Roland et al 2001).

**Technical outcomes**

*Functional gain*

Nine studies reported upon the mean functional gain provided by the MEI compared with the HA (Table 45). One study also compared the functional gain provided by two different digital audio processors (D type and Signia type) with that provided by an HA (Todt et al 2005). The gain provided by the D type at 500

Hz, 1, 2 and 4 kHz was 22.8 [6.5] dB and the gain provided by the Signia type was

29.8 [2.9] dB. The differences between the types were not statistically significant. As the D type processor was commonly employed in the included studies, the functional gain provided by this audio processor was detailed in Table 45.

#### Table 45 Mean functional gain provided by the middle ear implant versus the hearing aid in patients with sensorineural hearing loss

**Study ID HA gain MEI gain Details**

Chen 2004 20 dB 17 dB MEI produced less gain at frequencies 3000 Hz and higher compared to the HA (at 3000 Hz HA was

18.5 and MEI was 7)

Fraysse 2001 17 dB [SD 7-13 dB] 25 dB [SD 12-15 dB]

MEI provided clinically significant greater gain compared with the HA (*P*-value not provided)

Hough 2001 - - MEI provided overall 52% improvement (8.3 dB ±

3.9) in functional gain compared to the HA

Jenkins 2007 - - MEI performance significantly less than the patient’s own HA (*P*<0.05 for all frequencies but 4000 and

6000 Hz)

Luetje 2002 17.8 dB 31.2 dB MEI provided significantly more gain than HA (mean change was 14.1 dB, *P*<0.001)

Matthews 2002 14.6 dBa 22.4 dBa MEI provided mean 7.8 dB improvementa

Roland 2001 - - Average MEI improvement over HA across 500-

4000 Hz was 9.95 dB gain*.* At 6000Hz MEI had

21.1dB more gain compared to optimally for traditional hearing aids

Todt 2002 15.2 dB 24.3 dB -

Todt 2005 18.0 dB [SD 3.4 dB] 22.8 dBb [SD 6.5 - dB]

a: Estimated from figure

b: D type audio processor

dB decibels; HA: hearing aid; MEI: middle ear implant SD: standard deviation; - indicates not reported

One study noted that the lower functional gains noted in the HA may be due to patients’ inability to comfortably tolerate higher gain settings, due to feedback and distortion that may occur when amplification is increased (Hough et al 2001).

Two studies also assessed functional gain at individual frequencies (Fraysse et al

2001; Hough et al 2001). In the first study, in comparison to the HA the MEI with the D processor provided significantly greater gain for 7/9 measured frequencies (excluding 250 and 4000 Hz) (Fraysse et al 2001). The maximum gain provided at each frequency for the MEI was 20 dB to 25 dB better than the hearing aid at 500 to 2000 Hz and at 8000 Hz. Maximum gains at 3000 to 6000

Hz varied by 5 to 15 dB in favour of the MEI. The second study assessed functional gain of the MEI and the HA at 2000, 3000 and 4000 Hz (Hough et al

2001). The functional gain provided by the MEI at these frequencies was an average of 42 per cent higher than that obtained with the optimally fit HA (9.6 dB±7.4 dB).

*APHAB*

Four studies reported effectiveness outcomes of the MEI compared with the HA using the APHAB sub-scales (Chen et al 2004; Jenkins et al 2004; Snik et al 2007; Todt et al 2002) (Table 46). Two of these studies did not clearly state whether or not comparisons were made to an HA, although this appeared to be the case (Jenkins et al 2004; Snik et al 2007). One additional study provided an average measure across the EC, BN and RV subscales and found that the MEI provided a significant mean 7.2 point improvement over the HA (Matthews 2002).

#### Table 46 APHAB improvements of the middle ear implant compared with the hearing aid in patients with sensorineural hearing loss

|  |  |  |
| --- | --- | --- |
| **Study ID** | **Improvement after MEI implantation** | ***P-*value** |
| Background Noise (BN) |  |  |
| Jenkins 2004 | 45 point improvementa | - |
| Snik 2007 | 9.2% improvementb | *P*=0.03 |
| Todt 2002 | 37 point improvement | *P*<0.05 |
| Reverberation (RV) |  |  |
| Jenkins 2004  Snik 2007 | 44 point improvementa  12.7% improvementb | -  *P*=0.02 |
| Todt 2002 | 32 point improvement | *P*<0.05 |
| Ease of Communication (EC) | | |
| Jenkins 2004 | 55 point improvementa | - |
| Snik 2007 | 19.6% improvementb | *P*<0.001 |
| Todt 2002 | 27 point improvement | *P*<0.05 |
| Aversiveness (AV) |  |  |
| Chen 2004 | Approximate improvement over HA of 21% | ns |
| Jenkins 2004  Snik 2007 | 26 point improvementa  2.5% improvementb | -  ns |
| Todt 2002 | 35 point improvement | *P*<0.05 |

a: This study did not clearly state whether score was improvement over HA, or merely the score achieved with MEI

b: This study did not clearly state whether baseline was with or without HA

HA: hearing aid; MEI: middle ear implant; ns: not significant; - indicates not reported

Six further studies reported narrative effectiveness outcomes for the MEI compared with the HA using the APHAB (Chen et al 2004; Jenkins et al 2004; Jenkins et al 2007; Roland et al 2001; Thill et al 2002; Uziel et al 2003). Generally the MEI was preferred over the HA (Chen et al 2004; Jenkins et al 2004; Jenkins et al 2007; Thill et al 2002; Uziel et al 2003). One study found that patients reported significantly fewer difficulties in understanding speech with the MEI than they did with their preoperative HA (statistics not provided) (Thill et al

2002). A second study found that patients with severe HL reported greater benefit (*P*<0.001) of MEI on the EC, RV and BN subscales than the HA, but also experienced more aversiveness of sounds (Jenkins et al 2004). One study found

no significant differences between the MEI and HA for the EC, RV and BN

scales (Roland et al 2001).

*Hough Ear Institute Profile*

Three studies reported effectiveness outcomes using the Hough Ear Institute Profile (Hough et al 2001; Matthews 2002; Roland et al 2001). All patients had either moderate or severe SNHL. One study (n=10) reported that when using the MEI feedback was eliminated, the occlusive effect was reduced (data not provided) and the sound quality was increased by 27.3 per cent (±26.5 SD) (Hough et al 2001). It was unclear whether these improvements were compared with the unaided condition or with the HA. The overall subject satisfaction with the MEI improved 16.7 per cent over the HA condition.

The second study (n=103, 94 subjects responded) reported that the MEI was rated by 99 per cent of patients as having the least amount of feedback, but it was unclear whether this was in comparison to the unaided condition or to the HA (Matthews 2002). In terms of sound quality 89 per cent of subjects preferred the

MEI over their HA. Occlusion was reported by 54 per cent of patients with HA and by 23 per cent of patients with the MEI. Of 94 subjects responding, 89 per cent preferred the MEI (presumably to their HA) in terms of overall satisfaction.

The third study (n=23) found that although average daily use of the MEI or the HA did not vary for most patients, the MEI provided higher fidelity of sound and decreased feedback compared with the HA (no data provided) (Roland et al

2001). Sixteen patients reported feedback with the HA, and 14 of these patients noted that feedback was completely alleviated with the MEI. Twelve patients reported occlusion with the HA, and nine of these patients noted that occlusion was absent with the MEI. Overall satisfaction was approximately 32.6 per cent higher for the MEI than for the optimally fit HA. A total of 95.6 per cent of subjects noted overall preference for the MEI over the optimally fit HA (Roland et al 2001).

*PHAP*

One study reported effectiveness outcomes using the Profile of Hearing Aid Performance (PHAP) (Luetje et al 2002). The number of patients reporting improvement in scores was significantly more for the MEI than the pre-surgical HA in all seven subscales of the PHAP (*P*=0.001). The numbers of individuals reporting improvement of the MEI over the HA are detailed below:

o Familiar talkers: n=9 (18 per cent)

o Ease of communications: n=15 (30 per cent)

o Reverberation: n=24 (48 per cent)

o Reduced cues: n=18 (36 per cent)

o Background noise: n=28 (56 per cent)

o Aversiveness: n=21 (42 per cent)

o Distortion of sounds: n=17 (34 per cent)

*Speech discrimination*

Six studies reported upon the effectiveness of the MEI compared with the HA in terms of speech discrimination in quiet (Chen et al 2004; Hough et al 2001, Matthews 2002; Roland et al 2001; Snik and Cremers 2001; Todt et al 2002) (Table 47). Seven studies reported upon the effectiveness of the MEI compared with the HA in terms of speech discrimination in noise (Fraysse 2001; Matthews

2002; Roland 2001; Todt 2002; Todt 2005; Uziel 2003; Zenner 2003) (Table 48).

#### Table 47 Speech discrimination in quiet scores for the middle ear implant compared with the hearing aid in sensorineural hearing loss

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study ID** | **Presentation level** | **Speech disc.**  **HA** | **Speech disc.**  **MEI** | **Difference** |
| Chen 2004 | 50 dB | - | - | HA was >20% words better than the MEI at all follow-up times |
| Hough 2001 | - | - | - | MEI provided average 3.8% increase compared with the optimally fit HA |
| Jenkins 2004 | - | - | - | Speech recognition scores with the MEI were equivalent to those with the digital hearing aid, and both were significantly better (*P*<0.001) than those with the patients’ ‘walk-in’ hearing aid |
| Matthews 2002 | 63 dB SPL | - | - | MEI provided 5.3% increase compared to HA (stated to be significant, although statistical significance not provided) |
| Roland 2001 | - | - | - | No significant difference between MEI and  HA |
| Snik 2001 | 65 dB | 77.2%a | 67.4% | 4 of 5 patients had better scores with HA than MEI (3 patients *P*=0.05, one patient *P*<0.01) |
| Todt 2002 | 65 dB | 63% [8.0%] | 89% [2.9%] | MEI provided average 26% improvement compared to HA |
| Todt 2005 | 65 dB | 73% [8.0%] | 75% [10.4%] | - |
| Verhaegen 2009 | 65 dB | - | - | Scores with the VSB and Otologics MET were not better than those with a state-of- the-art BTE |

a: Calculated from data provided

BTE: behind the ear; dB: decibels; HA: hearing aid; MEI: middle ear implant; MET: Otologics Middle Ear Transducer; SPL: sound pressure level; Speech Disc.: speech discrimination; VSB: Vibrant Soundbridge; - indicates not reported

One study reported that in patients with SNHL without external otitis (thus allowing the use of a HA), the HA should be the first choice up to a SNHL of 95 dB HL (Verhaegen et al 2008).

#### Table 48 Speech discrimination in noise scores for the middle ear implant compared with the hearing aid in sensorineural hearing loss

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study ID** | **Presentation level** | **Speech disc.** | **Speech disc.** | **Difference** |
|  |  | **HA** | **MEI** |  |
| Fraysse 2001 | - | - | - | At the 50% discrimination level, the aided |
|  |  |  |  | condition with each device reveals |
|  |  |  |  | significant speech gain over the |
|  |  |  |  | preoperative unaided condition. |
|  |  |  |  | Speech gain was recorded as 13 dB with |
|  |  |  |  | the HA (*P*=0.033) and 12 dB with the |
|  |  |  |  | Vibrant D (*P*=0.017). |
| Matthews 2002 | 63 dB SPL | - | - | No significant difference |
| Roland 2001 | - | - | - | No significant difference |
| Todt 2002 | 65 dB | 62% [8.2%] | 74% [9.0%] | No significant difference |
| Todt 2005 | 65 dB | - | - | HA was 23% better than the MEI |
| Uziel 2003 | 60 dB SPL | - | - | Then SNR of which 50% correct word |
|  |  |  |  | score was achievable was significantly |
|  |  |  |  | lower when using the VSB compared to |
|  |  |  |  | the SIGNIA HA (*P*=0.028) |
| Zenner 2003a | 60-90 dB SPL | - | - | MEI provided ≥10% improvement over the  HAb |

a: MEI n=13, HA n=5

b: Estimated from figure

dB: decibels; HA: hearing aid; MEI: middle ear implant; SNR: signal to noise ratio; SPL: sound pressure level; - indicates not reported

*Hearing in Noise Test*

One study assessed patients using the Hearing in Noise Test HINT (Chen et al

2004). Only one patient was assessed. When compared to the HA, the subject’s ability to understand speech in quiet when using the MEI was improved by 88 per cent and in noise by 62 per cent.

*Revised Speech Perception In Noise*

Two studies reported outcomes using the Speech Perception in Noise (SPIN) test

(Hough et al 2001; Luetje et al 2002). In one study, sentences were presented in a

+8 signal-to-noise ratio to 10 patients (Hough et al 2001). An average of 17 per cent improvement in low predictability (LP) sentence scores (1.3 words correct with ±3.3 SD) was reported when the MEI was compared with those of the optimally fit HA (Hough et al 2001). The second study employed the Revised test (R-SPIN) in 50 patients who received the MEI with a D audio processor (Luetje et al 2002). After MEI implantation patients demonstrated a mean increase of six per cent in aided speech intelligibility in the presence of background noise. The mean change in LP word scores was not significant compared with HA scores. Individually, after MEI implantation 12 (24 per cent) showed a significant improvement, 31 (62 per cent) showed no significant change, and 7 (14 per cent) patients showed a decrease in LP word scores compared to their HA. The mean group LP score improved over the HA by a factor of 4.

*Speech reception threshold*

One study reported upon speech reception threshold after MEI implantation (Chen et al 2004). The MEI had a <5 dB improvement over the HA at four months post-implantation, and a <5 dB worsening at one and two months post-

implantation. The MEI had a >5 dB HL worsening at 10 months post- implantation. When measured at 65 dB, the MEI was not significantly better than the patient’s best-fit HA.

*Other audiological measures*

One study reported upon the articulation index (Hough et al 2001a). This study found that MEI implantation provided a clinically significant 13.1 per cent average improvement (±8.7 dB) over the HA value. Although no statistical significance

was provided, this improvement allowed increased availability in the 1000, 2000 and 3000 Hz frequencies which are important for speech understanding.

One study reported upon warble tone thresholds (Uziel et al 2003). This study found that warble tone thresholds with the HA and MEI were comparable across the test frequency range (*P*=0.14 – 0.91).

One study reported upon the use of Monaural Word scores (Jenkins et al 2007). In this study there was a significant difference in Monaural Word scores, where the hearing aid condition was better (*P*<0.001).

**Food and Drug Administration regulatory data: sensorineural hearing loss**

In addition to the 664 patients assessed in the 14 comparative studies, a regulatory document prepared for the US Food and Drug Administration (FDA) was identified (Symphonix Devices, Incorporated 2000). This study reported upon the effectiveness of the VSB MEI in comparison with the patient’s pre-surgical HA in a total of 54 patients with SNHL (see Table 49). The VSB was implanted with either the Vibrant P or the Vibrant D audio processor. As the Vibrant D represents a technological advance from the Vibrant P audio processor, only effectiveness data for the Vibrant D audio processor were extracted and included.

This study was produced by an MEI device manufacturer and was not published in a peer-reviewed journal. The study did not report upon study design (retrospective or prospective) or upon the method of patient enrolment. Both inclusion and exclusion criteria were provided. Patients were followed up for five months post-surgery plus an additional six weeks to allow acclimatisation to the audio processor. One patient was lost to follow-up as their MEI did not activate.

#### Table 49 FDA regulatory data for middle ear implant for sensorineural hearing loss

**Study ID N HL aetiology Surgical history**

**Mean age Gender**

**M/F**

**Mean preoperative PTA threshold**

**Previous HA**

**use**

Symphonix Devices, Incorporated

2000

54 Unknown:

44/54

Heredity:

5/54

Noise exposure:

2/54

Presbycusis:

1/54

Barotrauma:

1/54

Trauma: 1/54

- Age 28-44: 11 patients

Age 45-64: 23 patients

Age 65+: 20 patients

26/28 - Yes

HA: hearing aid; HL: hearing loss; PTA: pure-tone average; - indicates not reported

**Quality of life and satisfaction measures**

This document utilised the Hearing Device Satisfaction Score (HDSS)2 to assess patients hearing difficulties in various listening situations. No statistical tests were presented for quality of life or satisfaction measures after MEI implantation.

*HDSS*

At five months, a total of 86 per cent (42/49) of SNHL patients were satisfied with the clearness of sound and tone with the VSB compared to 31 per cent (15/49) who were satisfied with the clearness of sound and tone of their own hearing aids (Symphonix Devices, Incorporated 2000). Improvement in overall sound quality satisfaction with the VSB vs hearing aids was noted in 94 per cent (44/47) of patients. Meanwhile, 89 per cent (43/49) experienced improvement of their satisfaction rating for sound quality of their own voice with the VSB. The overall fit and comfort of the VSB was satisfactory in 98 per cent (48/49) of patients. In the subgroup of 11 patients who were dissatisfied with the fit and comfort of their conventional hearing aids, 100 per cent were satisfied with the VSB. In addition, 97 per cent (31/32) of patients who previously experienced acoustic feedback with their hearing aid reported substantial improvement (no acoustic feedback) with the VSB. The HDSS results indicated that maintenance was not a substantial concern in 98 per cent (45/46) of patients and all of the 14 patients who were previously dissatisfied with cleaning and maintenance of their hearing aids were satisfied with the VSB (Symphonix Devices, Incorporated

2000).

*General and unvalidated*

The FDA regulatory data (Symphonix Devices, Incorporated 2000) also utilised the unvalidated Soundbridge Hearing Aid Comparison Questionnaire (SHACQ)

2 Developed by Symphonix Devices.

and found that speech perception in a controlled environment was similar between the VSB and the patient’s own hearing aid. The SHACQ also indicated that the VSB was preferred over conventional hearing aids in several speech environments: 86 per cent (33/43) preferred VSB for speech outdoors, 95 per cent (41/43) preferred VSB in quiet environments, 88 per cent (35/40) preferred VSB for speech in restaurant, 86 per cent (38/44) preferred VSB for speech on

television and 88 per cent (45/40) preferred VSB for speech on radio (Symphonix

Devices, Incorporated 2000).

**Technical outcomes**

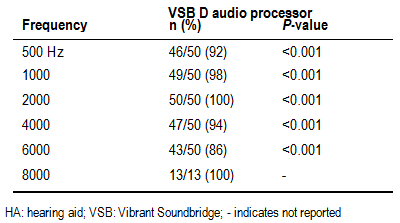
*Functional gain*

All patients demonstrated a higher gain with the MEI compared to the presurgical

HA. Patients showed statistically significant improvement at the frequencies 500,

1000, 2000, 4000 and 6000 Hz (Table 50).

#### Table 50 Number of patients experiencing functional gain with the VSB compared with pre-surgery external HA



*PHAP*

Effectiveness outcomes for this cohort were also reported using the Profile of Hearing Aid Performance (PHAP) (see Table 51). When assessed as a group, the authors observed a mean significant improvement with the VSB compared to pre- surgery HA on all seven subscales of the PHAP (statistical data not reported). When assessed individually, the authors reported significant improvements compared with pre-surgical HA. However, no statistical data to support this claim was presented.

#### Table 51 Individual PHAP scores for patients after VSB implantation

**PHAP Scale Patients with significant improvement**

Familiar talkers 9/50 patients (18%) Ease of communication 15/50 patients (30%) Reverberation 24/50 patients (48%) Reduced cues 18/50 patients (36%) Background noise 28/50 patients (56%) Aversiveness of sounds 21/50 patients (42%) Distortion of sounds 17/50 patients (34%)

**Effectiveness of the middle ear implant versus the external hearing aid:**

**mixed hearing loss**

Two comparative studies assessed the effectiveness of the MEI compared with the HA for MHL (Caye-Thomasen et al 2002; Tos et al 1994). These studies examined the same cohort of nine patients; one study assessed short-term outcomes (Tos et al 1994) and the other assessed long-term outcomes (Caye- Thomasen et al 2002) of the Heide system MEI. In all patients the MEI was modified to facilitate placement, which was difficult due to the conductive portion of the hearing loss. The hydroxylapatite shaft of the MEI was removed to avoid protrusion under the tympanic membrane.

Neither study reported upon study design (retrospective or prospective) or upon the method of patient enrolment. Neither inclusion nor exclusion criteria were provided. Three patients were lost to follow-up, and at mean 9.5 years six patients were available for follow-up (Caye-Thomasen et al 2002).

**Quality of life and satisfaction measures**

Neither of the studies reported upon quality of life or satisfaction measures.

**Technical outcomes**

*Functional gain*

The mean functional gain of the MEI was 31 dB and the mean MEI gain compared to the HA was 17.7 dB (no statistical data provided). However at mean

9.5 years follow-up, no patients used the MEI for various reasons including fitting problems (four patients), loss of the driver (one patient) and prosthesis dislocation (one patient). The mean time of MEI use was 24 months (3-60 months) (Caye- Thomasen et al 2002).

**Effectiveness of the middle ear implant versus the external hearing aid:**

**conductive hearing loss**

No comparative studies assessing the effectiveness of the MEI compared with the

HA for CHL could be identified.

**Effectiveness summary for middle ear implant vs external hearing aid**

*Sensorineural hearing loss*

Fourteen comparative studies reported upon the effectiveness of the MEI versus the HA in a total of 664 patients. Only four of these studies clearly stated that they used an optimal, best-fit, or state-of-the-art HA.

Quality of life and patient satisfaction measures: generally improvements were noted in all scores with MEI over baseline preoperative EHA. For the **HDSS** two studies found that patients reported an improvement in satisfaction with MEI over the HA. Significant improvements were noted in five patients (*P*<0.05).

Technical measures: Four of ten studies reported statistically significant improvements in **APHAB** with MEI compared with HA, while one study found no statistically significant differences between the MEI and HA. Nine studies reported upon **mean functional gain** after MEI implantation compared with the HA. One study found that MEI was significantly better than HA (*P*<0.001), while one study found that generally HA was significantly better than MEI (*P*<0.05). Of the remaining seven studies that reported upon this outcome six found that MEI was better than HA, although generally no clinically significant difference (≥10 dB) was seen. Three studies with a total of 127 patients reported outcomes using the **Hough Ear Institute Profile**. Generally subject satisfaction was higher with the MEI than with the HA, although no statistical analyses were performed. One study with 53 patients reported outcomes using **PHAP**. After MEI implantation a greater proportion of patients reported improvements in all seven PHAP subscales compared to their pre-surgery HA results (*P*=0.001). Nine studies reported upon **speech discrimination in quiet**. Three studies reported that the MEI was better than the HA, with improvements ranging from 5.3 per cent to 26 per cent. Two studies reported that the HA was better than the MEI, and reported significant improvements in four patients (three patients *P*=0.05; one patient *P*<0.01). The remaining studies did not report any significant differences between the MEI and HA. Six studies reported upon **speech discrimination in noise**. One study found that in noise, 50 per cent speech comprehension was achieved at significantly lower (more difficult) signal-to-noise ratios with the MEI than the HA (*P*=0.028). The remaining studies generally found that there was no significant difference between the MEI and HA. Outcomes for the **Hearing In Noise Test** were reported upon in one patient.

The patient reported improvements with MEI versus HA, although no statistical analysis was provided. Two studies reported upon patients using the **Revised Speech Perception In Noise** test. Neither study reported a significant improvement after MEI implantation compared with HA. One study reported outcomes using the **Speech Reception Threshold**. When measured at 65 dB the MEI was not significantly better than the patient’s best-fit HA.

In summary, the evidence assessing the effectiveness of the MEI compared with the HA provided varied outcomes. Generally the MEI appears to be at least as effective as the HA in patients with SNHL.

One additional comparative cohort reported effectiveness outcomes for the MEI

compared with the HA (Symphonix Devices, Incorporated 2000).

Quality of life and patient satisfaction outcomes: this document used the **HDSS** to assess patients. Improvements in HDSS score were noted after MEI implantation compared with the HA, although no statistical analysis was provided.

Technical measures: all patients demonstrated a higher **functional gain** with the MEI compared to the presurgical HA. Patients showed statistically significant improvement at the frequencies 500, 1000, 2000, 4000 and 6000 Hz (*P*<0.001). Significant mean and individual improvements were reported after MEI implantation compared with pre- surgical HA, although no statistical analyses were provided.

This reporting was supplied by an MEI device manufacturer, and was not published in a peer-reviewed journal. In summary this cohort of 54 patients with SNHL generally reported improvements after MEI implantation compared with the pre-surgical HA.

*Mixed hearing loss*

Two comparative studies reported upon the effectiveness of the MEI versus the HA. These studies both assessed the same cohort and provided short- and long-term outcomes in a total of nine patients. Neither of these studies clearly stated that they used an optimal, best-fit, or state-of-the-art HA.

Quality of life and patient satisfaction measures: neither study reported upon these outcomes.

Technical measures: the **mean functional gain** of the MEI was 31 dB. The mean MEI gain compared to the HA was 17.7 dB. A gain of ≥10 dB is considered clinically significant. Despite this gain at mean 9.5 years follow-up none of the patients used the MEI, and the mean length of use was 24 months (3-60 months).

In summary, the MEI demonstrated a mean functional gain compared with the HA in patients with MHL. However due to various fitting and extrusion issues, use of the MEI was discontinued by all nine patients.

### Other considerations

Three studies reported that a total of 48 patients elected to have the MEI rather than the BAHA due to reasons such as cosmetic issues, discomfort by pressure, and poor speech understanding when bone conduction was above 40 dB (Frenzel et al 2009; Streitberger et al 2009; Tringali et al 2009). Additionally, seven patients with unilateral microtia and osseous atresia elected to use the MEI rather than surgical atresia repair in conjunction with BAHA, although the reason for this was not provided (Frenzel et al 2009).

### Summary of effectiveness outcomes

The effectiveness conclusions drawn have been limited by the paucity of comparative studies. The evidence was unable to reliably inform upon the effectiveness of the MEI compared with the CI or the BAHA. Only one comparative study was available to assess the effectiveness of the MEI versus the comparators of interest (CI and BAHA).

**Effectiveness of the middle ear implant vs the cochlear implant in patients with sensorineural hearing loss of undefined severity**

One comparative study was assessed (NHMRC level III). Regarding projected speech recognition in patients with severe hearing loss, MEI appears to be less effective than CI. Regarding projected PS65 score in patients with mild, moderate or severe hearing loss, MEI appears to be less effective than CI.

As only one comparative study was available to inform upon the relative effectiveness of the MEI compared with the BAHA and the CI, absolute effectiveness outcomes were collated for the MEI implantation alone from 29

level IV studies. Of these 29 studies, seven were retrospective while the remaining were prospective studies. Sample sizes ranged from one to 125 patients; however, the majority of studies (22 out of 29) had less than 20 patients. Generally, improvements were seen when the MEI was implanted or activated.

**Effectiveness of the middle ear implant in patients with mild or moderate sensorineural hearing loss**

Four studies were available with a total of 50 patients. These included two comparative (level III) studies which reported on internal comparisons between different types of MEI and two case series (level IV). In summary, MEI appears to be effective in improving hearing from baseline, pre-implantation levels in patients with mild or moderate SNHL.

**Effectiveness of the middle ear implant in patients with severe sensorineural hearing loss**

One case series with a total of 13 patients was available for this indication. In summary, MEI appears to be effective in improving hearing from baseline, pre- implantation levels in patients with severe SNHL. Importantly, only a small number of patients were assessed and no statistical analyses were reported.

**Effectiveness of the middle ear implant in patients with sensorineural hearing loss of undefined severity**

Nine case series with a total of 262 patients were available for this indication, and statistical analyses were rarely provided to substantiate effectiveness outcomes. In summary, MEI appears to improve hearing in patients with SNHL of undefined severity. However, the data are of relatively low quality and outcome measures are variable between studies.

**Effectiveness of the middle ear implant in patients with mild or moderate mixed hearing loss**

Six case series with a total of 47 procedures in 46 patients were available for this indication. Two of the case series modified the MEI devices due to varied middle ear anatomy. In summary, generally MEI implantation or activation led to improvements in patients with mild or moderate MHL. Importantly, only a small number of patients were assessed and no statistical analyses were reported.

**Effectiveness of the middle ear implant in patients with severe mixed hearing loss**

Two case series which assessed a total of 47 patients were available for this indication. One case series modified the MEI devices due to varied middle ear anatomy. In summary, generally MEI implantation or activation led to improvements in patients with severe MHL. Importantly, only a small number of patients were assessed and few statistical analyses were reported.

**Effectiveness of the middle ear implant in patients with mixed hearing loss of undefined severity**

One case series with a total of 19 patients was available for this indication. This case series modified the MEI devices due to varied middle ear anatomy. In summary, generally MEI implantation led to improvements in patients with MHL of undefined severity. Importantly, only a small number of patients were assessed and few statistical analyses were reported.

**Effectiveness of the middle ear implant in patients with conductive hearing loss**

Two case series with a total of 12 patients who suffered from either unilateral osseous atresia or congenital auricular atresia were available for this indication. The implanted MEIs were modified to permit placement due to anatomic variation. In summary, 12 patients appeared to benefit from MEI implantation. However this evidence is limited by the small number of patients studied and

lack of statistical analysis. Additionally, these patients all suffered either unilateral osseous atresia or congenital auricular atresia, and it is unclear whether the benefits seen in these patients would extend to patients with other types of

CHL.

This report has been limited by the paucity of high-level evidence upon which to draw conclusions on the effectiveness of the MEI. Only one comparative study assessed the MEI versus the CI, and no comparative studies assessed the MEI versus the BAHA. Three additional included comparative studies used comparators which were not of relevance to this report. The remaining studies included to assess effectiveness were all case series, and subject to bias.

**Effectiveness of the middle ear implant vs the external hearing aid**

Fourteen comparative studies reported upon the effectiveness of the MEI versus the HA in a total of 664 patients. Only four of these studies clearly stated that they used an optimal, best-fit, or state-of-the-art HA. The evidence provided varied outcomes. However, generally the MEI appears to be at least as effective as the HA in patients with SNHL and MHL. No studies informed upon the effectiveness of the MEI versus the HA in patients with CHL.

The included studies displayed considerable variability regarding patient enrolment, study design, and length of follow-up. Several studies assessed the MEI in patients who had a range of hearing severities, such as mild to severe, which made meaningful reporting difficult for these various severities.

The included studies presented a variety of MEI devices. Most studies assessed the VSB MEI; however, the Otologics MET, Envoy Esteem, Rion device, SOUNDTEC DDHS, and TICA MEIs were also assessed. Additionally, some studies described instances in which the MEI attachment method or the devices themselves had been modified to permit implantation. Hence, differences in components and attachment occurred between the six identified different MEI devices and also between patients receiving the same MEI.

The majority of the available studies assessed the MEI in patients with SNHL. This is reflective of the anticipated Australian practice suggested by clinical experts.

The reporting of effectiveness outcomes was compromised by the lack of uniform outcome measurements. While the primary technical outcome measure (functional gain) was identified a priori, not all studies reported upon this outcome. Patient-related outcomes were not reported in all studies. Where these were reported, different outcome measures such as the GBI and the SF-36 were used.

Effectiveness outcomes were further compromised by the fact that some studies reported that baseline measurements were taken with a digital, best fit, or state- of-the-art HA, while others used the patient’s own HA. Further, in some before/after MEI studies it was not clearly stated whether baseline measures were measured with or without a HA. It appears that presently there is considerable variability in HA management prior to the consideration of MEI implantation.

### Expert opinion

Expert clinical opinion advises that of the three implanted hearing devices in question, the BAHA implantation involves the least invasive surgical procedure. The MEI implantation is considered to be more invasive than the BAHA, while the MEI and CI implantation are comparable in terms of surgical technique and complexity. Additionally, the CI is unlikely to be implanted in patients with mild or moderate hearing loss, as the implantation may cause further declines in hearing.

Expert clinical opinion advises that there is a significant risk of residual hearing loss in CI and MEI implantation, and that there is no risk of residual hearing loss in BAHA implantation.

Certain adverse events are likely to be more commonly seen in children. Paediatric bone is softer than that of adults, and has a longer osseointegration time. Hence, BAHAs implanted in children may be more susceptible to device loosening or damage. Loosening may also result from head trauma during rambunctious play. Children may also be less reliable at cleaning and maintaining their implant site, which may contribute to fixture loss.

Expert clinical opinion advises that the MEI is capable of providing better spatial hearing outcomes than those afforded by the BAHA. Additionally, the BAHA is reported to be less effective in treating SNHL.

It is likely that there is presently a sizeable, unaddressed pool of patients who may be eligible for MEI. This pool may exist for several reasons including patient comorbidities, inequity of service distribution, costs, cultural factors and waiting lists. It is likely that patients who are not presently accessing implantable devices will represent the largest uptake for leakage of MEI. This patient population is likely to be presently persisting with their hearing loss or with a poor hearing aid rather than using a CI or BAHA. Introduction of the MEI to the Australian

public health system will create a new indication for these patients, who may take this treatment option. Expert clinical opinion suggests that there may not be any cost savings associated with availability of MEI, only growth.

The Envoy Esteem device is currently undergoing clinical trials in the USK, USA and India, and Australian patients are travelling overseas to participate in these trials.

### What are the economic considerations?

Economic evaluation of new health care technologies is important when determining whether the new initiative offers additional benefits and at what cost. Economic evaluations are able to determine whether the new initiative is dominated by (or dominates) the existing technology, such that the costs are higher (lower) and the effectiveness is less (greater). Economic evaluation is particularly important when the new initiative offers health benefits at additional costs. Within a constrained health care budget, determining the additional cost that would be paid for a given health gain is important when ascertaining whether such incremental costs represent value for money.

The usual process for an economic evaluation is first to determine the incremental effectiveness, which is the additional benefits associated with the new technology relative to current practice. Secondly, to determine the incremental costs, this is

the difference in costs between the new initiative and current practice. Finally the incremental cost-effectiveness ratio (ICER) can be calculated using the following ratio:

*ICER =*

*Cost New – Cost Comparator*

*Effectiveness New – Effectiveness Comparator*

The ICER can then be compared to a threshold, or range of thresholds, to determine whether the health system should invest in the new technology.

If the technology is just as effective as the existing technology, then a cost- minimisation approach is warranted.

**Objective**

The objective of this section is to conduct an economic evaluation of MEI. The Advisory Panel decided that CI and BAHA would be the most appropriate comparators for the cost analysis.

**Search Strategies**

As described in the ‘approach to assessment’, a search strategy was developed to systematically identify studies in which MEI were used. Databases of peer- reviewed literature including Medline, PubMed, CINAHL and Cochrane have

been searched. The bibliographies of all retrieved publications were hand searched for any relevant references missing in the database search. Web-based searches included the Internet engines ‘Google’ and ‘Google scholar’.

In addition to the search terms described in the ‘approach to assessment’ section, Cost$ or Econ$ were added. This was to identify any published cost-effectiveness analysis. The inclusion and exclusion criteria remained the same.

**Background – evidence of cost-effectiveness**

One recent study was identified in the literature search pertaining to the cost- effectiveness of MEI. Using a retrospective design, Snik et al (2006) investigated the cost-effectiveness of middle ear implants in patients with moderate to severe SNHL and severe chronic external otitis. Of those patients who received an MEI,

13 were implanted with a Vibrant® Soundbridge® device and eight were implanted with an Otologics MET device. The outcome measure used in the study was quality adjusted life years (QALYs) derived from the SF-36 health survey. All patients were required to complete the questionnaire before implantation and post implantation.

Costs were limited to direct medical costs only. The authors estimated that on average, MEI implantation cost €14,354 (2006 prices = A$24,0763). The corresponding cost-utility ratio reported was €16,085 (A$27,686) per QALY gained. The authors suggest that this value is cost-effective when compared to CI (range of €12,107 (A$20,839) to €22,283 (A$38,354)).

A limitation of the Snik et al (2006) study is that only MEI patients were included, therefore the cost-effectiveness ratio represents the cost per QALY gained when compared to pre-treatment quality of life value. Preferably the authors should

have determined the incremental cost-effectiveness relative to an alternative treatment, such as CI or BAHA. Consequently in is not possible to determine the relative cost-effectiveness of MEI based on this study.

A second report from the Comité d’Evaluation et de Diffusion des Innovations

Technologiques in France also reviewed the economic considerations of MEI.

The estimated total costs of the procedure, including the device, implantation, and pre and post-surgery tests, was €10,000 (2002: A$17,591).4 The cost-effectiveness was not evaluated nor was a comparison made with other implantation devices or technologies.

**Rationale for the cost-effectiveness analysis**

The Advisory Panel decided that CI and BAHA would be the comparators for the cost analysis.

As previously discussed, no significant difference in the primary outcome was demonstrated between the MEI, CI or BAHA. Consequently, until more data are published supporting the superior effectiveness of one of the treatments for hearing loss, a cost-effectiveness analysis is not warranted. Therefore the aim of the present economic evaluation was to review the costs of MEI compared to BAHA and CI for the treatment of patients with SNHL, MHL and CHL when these interventions are provided under Australian conditions, and to provide an indication of the extent of uncertainty.

When comparing MEI with BAHA and CI it is important to note that in many cases BAHA and CI are not direct comparators to each other. This is summarised in Table 52. For SNHL the BAHA is a comparator when the condition is mild or moderate, whereas CI is the comparator when the condition is severe. Likewise

3 Exchange rate as of June 30, 2006: 1 Euro = $1.72 Australian

4 Exchange rate as of June 30, 2002: 1 Euro = $1.76 Australian

for MHL BAHA is a comparator when the condition is mild to moderate, whereas CI is the comparator when the condition is severe. For CHL BAHA is the only comparator, irrespective of hearing loss severity.

#### Table 52 Device applicability relative to type and severity of hearing loss

Sensorineural hearing loss

Conductive hearing loss

Mixed hearing loss

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | MEI | BAHA | CI | MEI | BAHA | MEI | BAHA | CI |
| Mild |  |  |  |  |  |  |  |  |
| Moderate  Severe |    |  |  |    |    |    |  |  |

Ranges include: Mild (20-39 dB), Moderate (40-69 dB) and Severe (70-94 dB)

MEI: middle ear implant, BAHA: bone anchored hearing aid), CI: cochlear implant

Profound hearing loss (95+ dB) is not included in this analysis

**Assumptions**

 The MEI is only considered applicable if a traditional HA is not suitable.

 Only hearing loss in the range from mild to severe is considered in this analysis.

Individuals with profound hearing loss would normally only be considered for a

CI and are therefore excluded.

 A limited societal perspective is used in the cost analysis, which includes patient co-payments.

 The replacement rate of MEI is uncertain; therefore, only costs incurred in the first year are included.

**Estimate of costs**

The estimated costs of MEI, BAHA and CI were taken from a number of sources. These included the Medicare Benefits Schedule (MBS), Australian Refined Diagnostic Related Group (AR-DRG) (D01Z version 5.1 round 11 – Private and Public), manufacturers’ implants and the median charged Medicare fee.

Resource use and MBS item numbers were determined by the Advisory Panel.

**Average costs per procedure**

*MBS items*

The MBS item fees represent the Government contribution to each procedure and were obtained from the MBS (see Table 53). The benefit amount and not the actual Medicare schedule fee were used in the model, as the patient usually receives a reimbursement of 75 per cent of the schedule fee for inpatient services and 85 per cent for outpatient services. Using the full fee would double count some of the copayment contribution.

*Average copayments*

Average copayments were sourced from the Department of Health and Ageing. The copayment component is calculated as the MBS fee charged minus the MBS benefit paid plus any additional specialist fees. It is possible that the copayment is not the entire patient contribution and it may also include some insurance

contribution (up to 25 per cent of the MBS fee for inpatient services). To avoid double counting, the 25 per cent insurance contribution is not included as a separate cost. The copayments are calculated as averages of all procedures claimed under the item number. Consequently there may be a degree of heterogeneity; therefore, the accuracy of the copayment is dependent on the other procedures that are also claimed under the same item number.

#### Table 53 MBS item numbers, fees and copayments

**MBS**

**MBS item Item # MBS fee schedule\* Copayment**

\* The MBS schedule is 75% of the MBS fee for inpatient services and 85% for outpatient services

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Level B GP consultation\*\* | 23 | $34.30 | $34.30 | $20.61 |
| Initial specialist consultation\*\* | 104 | $80.85 | $68.75 | $59.57 |
| Audiology service\*\* | 10952 | $58.85 | $50.05 | $32.19 |
| Neuromuscular electrodiagnosis\*\* | 11015 | $141.65 | $120.45 | $65.76 |
| Brain stem evoked audiometry\*\* | 11300 | $181.90 | $154.65 | $83.52 |
| Brief pre-anaesthesia consultation\*\* | 17610 | $40.60 | $34.55 | $40.39 |
| Anaesthesia initiation (ear) | 20120 | $93.50 | $79.50 | $194.59 |
| Anaesthesia initiation (cranial bone) | 20225 | $224.40 | $190.75 | $566.85 |
| Osseo-integration - implantation | 41603 | $476.20 | $407.10 | $629.36 |
| Osseo-integration - fixation | 41604 | $176.25 | $149.85 | $247.95 |
| Cochlear implant | 41617 | $1,791.15 | $1,343.40 | $1,645.95 |
| Assist at operation | 51303 | $358.23 | $268.68 | $179.25 |
| CT scan\*\* | 56016 | $290.00 | $246.50 | $113.22 |

\*\* These MBS items are undertaken in the outpatient setting and therefore will contribute to the extended safety net

*Mental Assessment*

The mental health assessment cost was estimated using the Manual of Resource Items and Their Associated Cost from Pharmaceutical Benefits Advisory Committee guidelines.5 The cost of a clinical psychologist / clinical counsellor appointment ($122.50 for an initial consultation) was obtained from the Department of Veteran Affairs (DVA) fee schedule for allied health practitioners.

*Implant Costs*

The costs of the CI and BAHA can be divided into the implant cost and processor cost. Both were sourced directly from the manufacturer, Cochlear Australia & New Zealand.6 The cost of the MEI was provided by Life Systems Medical Pty Ltd.7 The following costs, including the implant and processor, were obtained: $25,070 (CI), $8,830 (BAHA) and $14,400 (MEI).

*Hospital Stay*

The average per diem cost for hospitalisation was derived from the AR-DRG information for DRG D01Z (version 5.1 round 11 – Private and Public) for CI. The Advisory Panel indicated that a one-night hospital stay would be necessary

5 Pharmaceutical Benefits Advisory Committee: http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pbs-general-pubs-pharmpac- gusubpac.htm

6 Cochlear Australia & New Zealan[d: http://www.cochlear.com/au/](http://www.cochlear.com/au/)

7 Vibrant® Soundbridge®: Life Systems Medical Pty Ltd., Australia

for all MEIs and 90 per cent of CIs. BAHA would be administered as an inpatient procedure but not require a hospital stay.

*Battery costs*

Battery life for each of the devices depends on the individual usage. It was assumed the CI battery would last four days, BAHA seven days and MEI seven days. The costs of batteries were sourced from two online distributors of hearing aid batteries. The cost for a pack of 12 batteries is $9.168, and 60 batteries is

$45.00.9 Therefore the unit cost of each battery is $0.76 and $0.75, respectively.

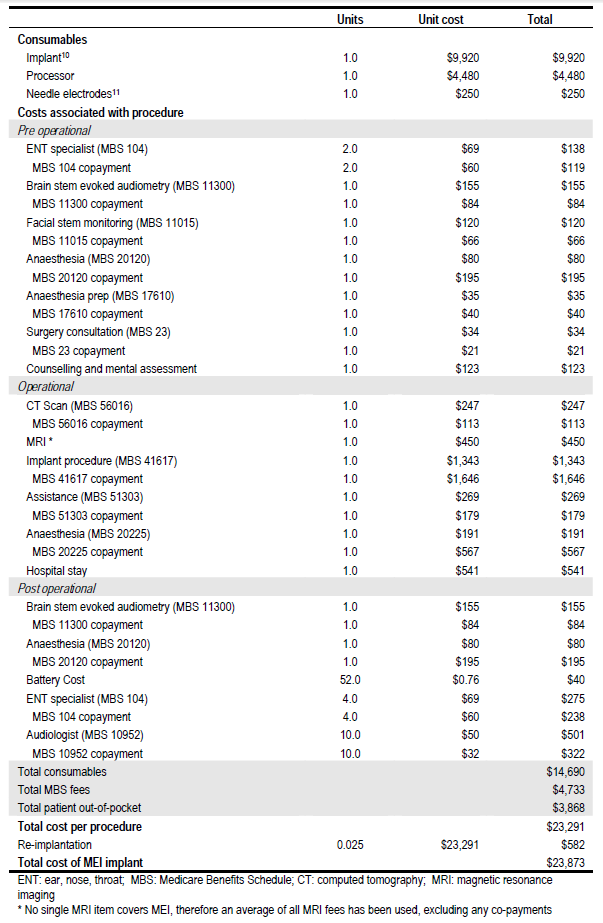
*Re-implantation costs*

The Advisory Panel provided estimates of the failure rates for each device. The failure rates used in the model were: 1 per cent CI, 2.5 per cent MEI and 5 per cent BAHA. These are tested in the sensitivity analysis. The re-implantation costs are estimated to be the same as the initial procedure. This may be an overestimation of the total cost of re-implantation as some items and tests may not be repeated. On the other hand the estimate does not include the removal of the failed device.

8 Microbattery.com: [http://shopping.microbattery.com](http://shopping.microbattery.com/)

9 The Audio Store Hearing Clinic: [www.theaudiostore.com.au](http://www.theaudiostore.com.au/)

#### Table 54 Calculation of average costs for MEI

10 Vibrant® Soundbridge®

11 Expert opinion from advisory panel

#### Table 55 Calculation of average costs for BAHA

**Consumables**

**Units Unit cost Total**

Processor12 1.0 $6,900 $6,900

Needle electrodes 1.0 $250 $250

Abutment Snap Coupling 1.0 $1,930 $1,930

**Costs associated with procedure**

*Pre operational*

ENT specialist (MBS 104) 2.0 $69 $138

MBS 104 copayment 2.0 $60 $119

Brain stem evoked audiometry (MBS 11300) 0.0 $155 $0

MBS 11300 copayment 0.0 $84 $0

Facial stem monitoring (MBS 11015) 1.0 $120 $120

MBS 11015 copayment 1.0 $66 $66

Anaesthesia (MBS 20120) 0.0 $80 $0

MBS 20120 copayment 0.0 $195 $0

Anaesthesia prep (MBS 17610) 1.0 $35 $35

MBS 17610 copayment 1.0 $40 $40

Surgery consultation (MBS 23) 1.0 $34 $34

MBS 23 copayment 1.0 $21 $21

Counselling and mental assessment 1.0 $123 $123

*Operational*

CT Scan (MBS 56016) 1.0 $247 $247

MBS 56016 copayment 1.0 $113 $113

MRI \* 1.0 $450 $450

Assistance (MBS 51303) 1.0 $269 $269

MBS 51303 copayment 1.0 $179 $179

Anaesthesia (MBS 20225) 1.0 $191 $191

MBS 20225 copayment 1.0 $567 $567

Osseointegration procedure (MBS 41603) 1.0 $407 $407

MBS 41603 copayment 1.0 $629 $629

Osseointegration procedure (MBS 41604) 1.0 $150 $150

MBS 41604 copayment 1.0 $248 $248

Hospital stay 1.0 $541 $541

*Post operational*

Brain stem evoked audiometry (MBS 11300) 0.0 $155 $0

MBS 11300 copayment 0.0 $84 $0

Battery Cost 52.0 $0.76 $40

ENT specialist (MBS 104) 4.0 $69 $275

MBS 104 copayment 4.0 $60 $238

Audiologist (MBS 10952) 2.0 $50 $100

MBS 10952 copayment 2.0 $32 $64

Total consumables $9,120

Total MBS fees $3,078

Total patient out-of-pocket $2,285

**Total cost per procedure** $14,483

Re-implantation 0.05 $14,483 $724

**Total cost of BAHA** $15,207

ENT: ear, nose, throat; MBS: Medicare Benefits Schedule; CT: computed tomography; MRI: magnetic resonance imaging

\* No single MRI item covers MEI, therefore an average of all MRI fees has been used, excluding any co-payments

12 Cochlear Australia & New Zealan[d: http://www.cochlear.com/au/](http://www.cochlear.com/au/)

#### Table 56 Calculation of average costs for CI

**Consumables**

**Units Unit Cost Total**

Implant13 1.0 $13,570 $13,570

Processor 1.0 $11,500 $11,500

Needle electrodes 1.0 $250 $250

**Costs associated with procedure**

*Pre operational*

ENT specialist (MBS 104) 2.0 $69 $138

MBS 104 copayment 2.0 $60 $119

Brain stem evoked audiometry (MBS 11300) 1.0 $155 $155

MBS 11300 copayment 1.0 $84 $84

Facial stem monitoring (MBS 11015) 1.0 $120 $120

MBS 11015 copayment 1.0 $66 $66

Anaesthesia (MBS 20120) 1.0 $80 $80

MBS 20120 copayment 1.0 $195 $195

Anaesthesia prep (MBS 17610) 1.0 $35 $35

MBS 17610 copayment 1.0 $40 $40

Surgery consultation (MBS 23) 1.0 $34 $34

MBS 23 copayment 1.0 $21 $21

Counselling and mental assessment 1.0 $123 $123

*Operational*

CT Scan (MBS 56016) 1.0 $247 $247

MBS 56016 copayment 1.0 $113 $113

MRI \* 1.0 $450 $450

Implant procedure (MBS 41617) 1.0 $1,343 $1,343

MBS 41617 copayment 1.0 $1,646 $1,646

Assistance (MBS 51303) 1.0 $269 $269

MBS 51303 copayment 1.0 $179 $179

Anaesthesia (MBS 20225) 1.0 $191 $191

MBS 20225 copayment 1.0 $567 $567

Hospital stay 0.9 $541 $487

*Post operational*

Brain stem evoked audiometry (MBS 11300) 1.0 $155 $155

MBS 11300 copayment 1.0 $84 $84

Anaesthesia (MBS 20120) 1.0 $80 $80

MBS 20120 copayment 1.0 $195 $195

Battery Cost 122.0 $0.76 $93

ENT specialist (MBS 104) 4.0 $69 $275

MBS 104 copayment 4.0 $60 $238

Audiologist (MBS 10952) 12.0 $50 $601

MBS 10952 copayment 12.0 $32 $386

Total consumables $25,413

Total MBS fees $4,779

Total patient out-of-pocket $3,932

**Total cost per procedure** $34,124

Re-implantation 0.01 $34,124 $341

**Total cost of CI implant** $34,466

ENT: ear, nose, throat; MBS: Medicare Benefits Schedule; CT: computed tomography; MRI : magnetic resonance imaging

\* No single MRI item covers MEI, therefore an average of all MRI fees has been used, excluding any co-payments

13 Cochlear Australia & New Zealan[d: http://www.cochlear.com/au/](http://www.cochlear.com/au/)

**Average costs of each procedure**

The total estimated first year cost of an MEI, BAHA and CI is $23,873, $15,207 and $34,466, respectively (see Table 57). The incremental cost of using an MEI as opposed to a BAHA is $8,666. The incremental cost saving of using an MEI as opposed to a CI is $10,593. See Table 54, Table 55 and Table 56 for a complete breakdown of the costs.

The main difference between the cost of the MEI, CI and BAHA procedures is the cost of the implants and processors. The MBS and patient out-of-pocket costs are also lower for BAHA; however, this is offset somewhat by the higher

re-implantation rate.

|  |  |  |  |
| --- | --- | --- | --- |
| Table 57 Average costs per procedure |  | | |
|  | **MEI** | **BAHA** | **CI** |
| Total consumables | $14,690 | $9,120 | $25,413 |
| Total MBS fees | $4,733 | $3,078 | $4,779 |
| Total patient out-of-pocket | $3,868 | $2,285 | $3,932 |
| **Total cost per procedure** | **$23,291** | **$14,483** | **$34,124** |
| Re-implantation | $582 | $724 | $341 |
| **Total cost of device** | **$23,873** | **$15,207** | **$34,466** |
| *Incremental cost (MEI vs BAHA/CI)* |  | $8,666 | -$10,593 |

BAHA: bone anchored hearing aid; CI: cochlear implant; MBS: Medicare Benefits Schedule; MEI: middle ear implant

**Implication to the extended safety net**

MBS items 23, 104, 10952 and 56016 are all performed in the outpatient setting. Therefore any out-of-pocket cost associated with these items will contribute towards the Extended Medicare Safety Net (EMSN). The total out-of-pocket cost for these items is $225.59, which is below the $1126 threshold ($562.90 for concession card holders). Consequently, out-of-pocket contributions for MEI, CI or BAHA procedures are unlikely to impact upon the EMSN.

**Sensitivity analysis**

In the sensitivity analysis a worst case scenario approach was adopted. In the worst case the number of ear, nose and throat (ENT) visits would increase from two to three visits, battery life would increase to two batteries per week instead of one, the number of audiologist visits would double, the nights in hospital was estimated using DRG average length of stay and the failure rates would change to

5 per cent for MEI, 10 per cent for BAHA and 5 per cent for CI.

#### Table 58 Average total costs for MEI, BAHA and CI

|  |  |  |
| --- | --- | --- |
|  | **Base Case** | **Worst Case** |
| MEI | $23,873 | $26,942 |
| BAHA | $15,207 | $16,028 |
| CI | $34,466 | $38,491 |

BAHA: bone anchored hearing aid; CI: cochlear implant; MEI: middle ear implant

Table 58 demonstrates that the costs are insensitive to these changes. The main contributor to the overall costs of each procedure is the implant and processor costs. For example, in the case of the CI, approximately 74 per cent of the total cost is due to the implant and processor. Therefore, adjusting the other parameters has little impact on the overall cost estimate in the first year.

**Other cost considerations**

Only the costs incurred in the first year were included in the analysis. This is due to the uncertainty in the future costs. The expected life of a CI is 20 to 30 years. In the application, the life-expectancy of the MEI is estimated to be 24 years; however, the validity of the value is unknown at this point. Other considerations are the replacement of the sound processor for both the CI and MEI. In the application it is suggested that this should occur every six years.

**Financial implications**

The number of potential candidates for an MEI can be estimated in a number of ways. For the primary analysis the number of procedures currently performed in Australia was estimated using 2006-07 MBS codes for BAHA and CI. In the sensitivity analysis the method proposed in the application was repeated using the prevalence of hearing loss in the Australian population.

In 2006-07 the number of CIs performed in Australia was as follows: MBS

41617=397, MBS 41603=106 and MBS 41604=101. One problem with using these data is that CI is used for severe and profound hearing loss. However MEI is not suitable for profound hearing loss, therefore the expected number of individuals treated for profound hearing loss needs to be subtracted from these

values. In the absence of Australian data, the estimated prevalence of severely and profound hearing loss in the UK was used to estimate the proportion of profound hearing loss14. Based on these data it was estimated that 17.6 per cent of CI are for profound hearing loss. Overall it is estimated that 327 individuals are suitable for an MEI (ie treatment of severe hearing loss).

It was assumed that all individuals receiving BAHA would be suitable for MEI (106 patients).

Based on these data, the total cost of BAHA would be $1,611,957 (106 patients) and the total cost of CI would be $11,270,250 (327 patients), resulting in a total cost of $12,882,207. If MEI was used instead of BAHA and CI the total cost would be $10,336,916. Hence the cost savings of performing MEI as a direct replacement for BAHA and CI would be $2,545,291.

These figures are based on 2006-07 data, therefore future projections are uncertain.

14 The Royal National Institute for Deaf People:

<http://www.rnid.org.uk/information_resources/aboutdeafness/statistics/statistics.htm>

#### Table 59 Incremental costs per procedure using MBS data

|  |  |  |  |
| --- | --- | --- | --- |
|  | **MEI** | **BAHA** | **CI** |
| Total cost per patient | $23,873 | $15,207 | $34,466 |
| Number of patients | 433 | 106 | 327 |
| *Breakdown of financial implications:* |  |  |  |
| Consumables | $6,519,653 | $1,015,022 | $8,393,193 |
| MBS items | $2,100,738 | $342,593 | $1,578,451 |
| Patient out-of-pocket | $1,716,524 | $254,342 | $1,298,605 |
| **Total financial implications** | **A=$10,336,916** | **B=$1,611,957** | **C=$11,270,250** |
| *Incremental costs:* |  |  |  |
| Consumables  MBS items | -$2,888,562  $179,694 |  |  |
| Patient out-of-pocket  **Total cost savings A-(B+C)** | $163,577  **-$2,545,291** |  |  |

BAHA: bone anchored hearing aid; CI: cochlear implant; MBS: Medicare Benefits Schedule; MEI: middle ear implant

As can be seen in Table 59 the bulk of the cost savings are due to reduced consumable costs. There would be a slight increase in the costs borne by the patient and the government.

One possible limitation to using MBS codes for CI and BAHA is the possibility of underestimating the total number of people suitable for MEI. This is because the MBS codes for CI numbers do not include severe patients with conductive

hearing loss. Also, there remains a question as to whether BAHA is appropriate for sensorineural patients, or if there is an unaddressed pool of candidates with mild or moderate sensorineural hearing loss that would benefit from MEI instead of a BAHA. Since sensorineural is a significant portion of all hearing loss, this could result in an underestimate of the number of candidates for MEI.

The proportion of CIs undertaken on profoundly deaf individuals was uncertain; therefore, a second analysis was undertaken. Based on expert opinion, the number of CIs performed each year for profound hearing loss was estimated to be 60 per cent. Using these data the estimated number of eligible patients for MEI would be

265 (106 BAHA and 159 CI).

#### Table 60 Incremental costs per procedure using MBS data (lower number of CI)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **MEI** | **BAHA** | **CI** |
| Total cost per patient | $23,873 | $15,207 | $34,466 |
| Number of patients | 265 | 106 | 159 |
| *Breakdown of financial implications:* |  |  |  |
| Consumables | $3,990,088 | $1,015,022 | $4,081,094 |
| MBS Items | $1,285,671 | $342,593 | $767,504 |
| Patient out-of-pocket | $1,050,529 | $254,342 | $631,432 |
| **Total financial implications** | **A=$6,326,288** | **B=$1,611,957** | **C=$5,480,030** |
| *Incremental costs:* |  |  |  |
| Consumables  MBS Items | -$1,106,028  $175,574 |  |  |
| Patient out-of-pocket  **Total cost savings A-(B+C)** | $164,755  **-$765,699** |  |  |

BAHA: bone anchored hearing aid; CI: cochlear implant; MBS: Medicare Benefits Schedule; MEI: middle ear implant

As can be seen in Table 60, when MEI replaces a lower number of CI the cost savings is reduced to $765,699. As before, the majority of cost savings is associated with a reduction in consumables.

**Sensitivity analysis of financial implications**

In the application it was estimated that 144 patients would be suitable for an MEI each year. Using the same methodology as the Applicant, but with 2009 ABS data, the number of suitable MEI patients was re-calculated as follows. Firstly, the prevalence of hearing loss was obtained from Listen Hear! Report (Access Economics, 2006). Secondly, the total number of individuals with sensorineural hearing loss was estimated to be 90 per cent of all hearing loss. Thirdly, it was estimated that 0.8 per cent of sensorineural hearing loss patients would be suitable for an MEI (Jenker et al 2002). Finally, it was estimated that 0.5 per cent had external otitis, therefore a traditional hearing aid would not be suitable.

Using this methodology, 149 candidates would require an MEI each year. Without MEI, 36 would require a BAHA and 113 would require a CI (based on MBS ratios). Based on these data, the total cost of BAHA would be $554,692 (36 patients) and the total cost of CI would be $3,878,215 (113 patients). This gives a total cost of $4,432,907. If MEI was used instead of BAHA and CI the total cost would be $3,557,045. Hence the cost savings of performing MEI as a direct replacement for BAHA and CI would be $875,862.

#### Table 61 Incremental costs per procedure using the method proposed by the Applicant

|  |  |  |  |
| --- | --- | --- | --- |
|  | **MEI** | **BAHA** | **CI** |
| Total cost per patient | $23,873 | $15,207 | $34,466 |
| Number of patients | 149 | 36 | 113 |
| *Breakdown of financial implications:* |  |  |  |
| Consumables | $2,243,483 | $349,280 | $2,888,189 |
| MBS items | $722,887 | $117,890 | $543,162 |
| Patient out-of-pocket  **Total financial implications** | $590,675  **A=$3,557,045,** | $87,522  **B=$554,692** | $446,864  **C=$3,878,215** |
| *Incremental costs:* |  |  |  |
| Consumables | -$993,986 |  |  |
| MBS items | $61,835 |  |  |
| Patient out-of-pocket | $56,289 |  |  |
| **Total cost savings A-(B+C)** | **-$875,862** |  |  |

BAHA: bone anchored hearing aid; CI: cochlear implant; MBS: Medicare Benefits Schedule; MEI: middle ear implant

**Further considerations**

The analysis thus far has demonstrated that if MEI is used as a direct replacement for CI there will be a cost saving, but if MEI replaces BAHA there will be an increase in cost. Since, in general, more CIs are performed there is an overall cost saving.

However, an issue arises if a pool of individuals exists who would elect to have an MEI and would previously not have had a CI or BAHA. This could include people who are not satisfied with a traditional hearing aid. Estimating this pool of individuals is difficult due to lack of data. Using the Applicant’s estimate, the number of suitable MEI candidates with moderate or severe hearing loss is 9613.

However, as this is the overall number in Australia, and not the number of people

who would receive the procedure in a given year, using this estimate per annum is an over-estimate.

An incremental analysis is presented in Table 62. This analysis is provided as an illustration only. The possible new candidates for MEI are estimated as follows: 1) only individuals with moderate or severe hearing loss are included, since individuals with mild hearing loss are unlikely to elect to have MEI; and 2) individuals with otitis media are removed, because these individuals have been included in the initial analysis.15 Of the remaining individuals it is estimated that between one per cent and five per cent may choose an MEI if available.

#### Table 62 Additional cost per annum for MEIs elected from an unaddressed pool that would not have been treated with either a BAHA or CI

|  |  |  |
| --- | --- | --- |
| **Estimated percentage electing for an MEI** | **Possible new candidates\*** | **Additional cost per annum\*\*** |
| 1% | 96 | $2,291,787 |
| 2% | 192 | $4,583,575 |
| 3% | 288 | $6,875,362 |
| 4% | 385 | $9,191,022 |
| 5% | 481 | $11,482,809 |

\*Estimates exclude patients with external otitis

\*\*Does not include cost of hearing aids avoided

MEI: middle ear implant

Based on these estimates, if one per cent of the estimated pool of individuals with moderate or severe hearing loss elected to have MEI, the additional cost would be

$2,291,787. These estimates are based on prevalence data of hearing loss in Australia and include a large portion of older Australians for whom an MEI would not be viable.

It is worth noting that if people elect to have an MEI in place of a hearing aid, there would be a cost saving from each hearing aid avoided that would reduce these overall cost estimates. For example, if a hearing aid costs $5000 per patient, the additional cost would be reduced to ($2,291,787-$480,000) = $1,811,787. However this may not be appropriate, as all patients may already have a hearing aid and the cost becomes a sunk cost.

15 It is estimated that 17.6% of individuals classified with severe hearing loss, actually have profound hearing loss. This number was subtracted from the total estimates. (based on UK data:<http://www.rnid.org.uk/information_resources/aboutdeafness/statistics/statistics.htm> )

## Discussion

### Limitations of the evidence

This report has been limited by the paucity of high-level evidence upon which to draw conclusions on the relative safety and effectiveness of the MEI. Only one comparative study assessed the MEI versus the CI, and no comparative studies assessed the MEI versus the BAHA. Three additional included comparative studies used comparators which were not of relevance to this report. The remaining studies included to assess effectiveness outcomes for the MEI were all case series, and subject to bias. The lack of high level evidence is likely related to the relative youth of the MEI procedure, and also to ethical issues regarding randomising patients to receive different types of surgical implantation.

The included studies displayed considerable variability regarding patient

enrolment, study design and length of follow-up. Several studies assessed the MEI in patients who had a range of hearing severities, such as mild to severe, which made meaningful reporting difficult for these various severities.

The included studies presented a variety of MEI devices. While most studies assessed the VSB MEI, the Otologics MET, Envoy Esteem, Rion device, SOUNDTEC DDHS, and TICA MEIs were also assessed. Additionally, some studies described instances in which the MEI attachment method or the devices themselves had been modified to permit implantation. Hence, differences in components and attachment occurred between the six identified different MEI devices and also between patients receiving the same MEI.

### Safety

No comparative evidence reporting on the safety of MEI compared with CI or BAHA was available. RCT evidence based on defined patient populations would better inform on any safety differences between MEI and the comparator procedures. In the absence of comparative safety data, information on the absolute safety of MEI, BAHA and CI implantation were included in this report. Even with the limitations in inclusion criteria for BAHA and CI data, much more evidence in terms of absolute patient numbers was available for CI. This reflects the fact that MEI is in its infancy compared with other more established alternatives.

Not all safety outcomes were uniformly reported across the identified studies. To address this, event rate has been reported in two manners throughout the report, both of which may be at risk of bias. The rate has been presented as a proportion of patients in the studies which specifically reported this outcome, which may be an over-inflated representation of the outcome, especially for rare events. The rate has also been presented as a proportion of the total patient number in all studies included for safety. This may be an under-representation of some outcomes, such as common outcomes which may not have been of interest in all studies (such as mild pain or infection).

Owing to the surgical techniques used, the devices implanted and the sites of implantation, several adverse events which were reported in BAHA or CI implantation were not encountered in MEI implantation. Several intracranial adverse events which were reported in CI patients were absent in MEI patients, including meningitis (which led to two deaths in children), dural damage and cerebrospinal fluid leak. The BAHA appeared to be more susceptible than the MEI to damage or loss due to trauma. Device loss due to trauma was not encountered in the MEI studies yet 3.72 per cent of all implanted BAHAs were lost for this reason, and osseointegration was lost due to trauma in 1.62 per cent of all implanted BAHAs. Once positioned, the MEI appeared to be more stable than the BAHA. Although a small percentage of all MEIs migrated, loss of osseointegration or failed osseointegration was quite commonly encountered in the BAHA studies. Generally, BAHA patients reported more wound healing

difficulty than MEI patients. This is likely to be due to the skin grafts employed in BAHA implantation, as well as the additional maintenance care required for the BAHA’s abutment area.

Conversely, several adverse were reported more frequently in MEI implantation than in BAHA or CI implantation. The incidence of tympanic membrane perforation was higher in MEI patients (0.7 per cent) than in CI patients (0.06 per cent), and did not occur in BAHA patients. Haematomae occurred more frequently in MEI patients (1.2 per cent) than in CI patients (0.02 per cent). Extrusions also occurred more frequently in MEI than in CI patients, and were not reported to have occurred in BAHA patients. Insufficient gain was more prevalent in MEI studies (1.6 per cent of all patients receiving MEI) than in BAHA studies (0.48 per cent of all patients receiving BAHA). Insufficient gain was not reported in CI patients. The BAHA devices appeared to be the most technologically consistent of the three devices, with no reported instances of BAHA device malfunction or failure compared with 1.3 per cent of all CI devices and 0.9 per cent of all MEI devices implanted.

Residual hearing loss after implantation was an important adverse event which was uniquely reported in MEI patients. Residual hearing loss was reported upon by most MEI studies, with thirteen studies reporting that patients suffered significant declines in mean residual hearing loss after MEI implantation. Unlike the CI literature, the MEI literature included many patients with mild or moderate HL. In these patients, any further deterioration in hearing may be of greater clinical importance compared with losses in patients with severe or profound HL. Patients with CHL did not report significantly worse residual hearing after implantation.

Expert clinical opinion endorsed by the Advisory Panel notes that certain adverse events are likely to be more commonly seen in children than in adults. Paediatric bone is softer than that of adults, and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage. Additionally, children may be likely to sustain head trauma during rambunctious play. Children may also be less reliable at cleaning and maintaining their implant site. This may be especially important in the case of the BAHA.

Communication with the manufacturer of the VSB device (Med-EL) indicates that this MEI is not MRI safe at any Tesla level, and can be removed if necessary.

Due to the differences in devices and the surgical procedures associated with them, the adverse events differ between MEI and its comparators. Overall, absolute evidence from case series studies suggests that MEI appears to be as safe as CI and BAHA.

### Effectiveness

Generally, MEI implantation and/or activation led to improvements in patients with SNHL, MHL and CHL. However, these conclusions are limited by the paucity of high-level evidence. Only one comparative study assessed the MEI versus the CI, and no comparative studies assessed the MEI versus the BAHA. Three additional included comparative studies used comparators which were not of relevance to this report. The remaining studies included to assess effectiveness were all case series, and subject to bias.

The included studies displayed considerable variability regarding patient

enrolment, study design and length of follow-up. Several studies assessed the MEI in patients who had a range of hearing severities, such as mild to severe, which made meaningful reporting difficult for these various severities.

The included studies presented a variety of MEI devices. While most studies assessed the VSB MEI, the Otologics MET, Envoy Esteem, Rion device, SOUNDTEC DDHS, and TICA MEIs were also assessed. Additionally, some studies described instances in which the MEI attachment method or the devices themselves had been modified to permit implantation. Hence, differences in components and attachment occurred between the six identified different MEI devices and also between patients receiving the same MEI.

The majority of the available studies assessed the MEI in patients with SNHL. This is reflective of the anticipated Australian practice suggested by clinical experts.

The reporting of effectiveness outcomes was compromised by the lack of uniform outcome measurements. While the primary technical outcome measure

(functional gain) was identified a priori, not all studies reported upon this outcome. Patient-related outcomes were not reported in all studies. Where these were reported, different outcome measures such as the GBI and the SF-36 were used.

Effectiveness outcomes were further compromised by the fact that some studies reported that baseline measurements were taken with a digital, best fit, or state-of- the-art HA, while others used the patient’s own HA. Further, in some

before/after MEI studies it was not clearly stated whether baseline measures were measured with or without a HA. It appears that presently there is considerable variability in HA management prior to the consideration of MEI implantation.

### Cost-effectiveness

The objective of the economic evaluation was to compare the cost-effectiveness

of MEI relative to BAHA and CI. In the absence of conclusive effectiveness data, a cost analysis was conducted to compare the different costs associated with each of the three procedures.

The estimated costs of MEI, BAHA and CI were taken from a number of sources. These included the Medicare Benefits Schedule (MBS), Australian Refined Diagnostic Related Group (AR-DRG) cost, manufacturer’s implants and the median charged MBS fee.

Based on a number of estimates and assumptions:

 The total estimated first year cost of an MEI, BAHA and CI is $23,873,

$15,207 and $34,466, respectively. The incremental **cost** of using an MEI as opposed to a BAHA is $8,666. The incremental **cost saving o**f using an MEI as opposed to a CI is $10,593.

 Based on 2006-07 MBS data, the total cost of BAHA would be $1,611,957 (106 patients) and the total cost of CI would be $11,270,250 (327 patients). This gives a total cost of $12,882,207. If MEI was used instead of BAHA and CI the total cost would be $10,336,916. Hence the cost savings of performing MEI as a direct replacement for BAHA and CI would be over $2.5 million.

 Expert opinion endorsed by the Advisory Panel indicated that MEI would not just replace current CI and BAHA use, but would become another option in meeting the pool of unmet need of those with hearing loss. Expert opinion was that these individuals, currently persisting with hearing loss or a less than optimal hearing aid, may consider MEI implantation while they are not considering or accessing BAHA or CI. The previously mentioned variablility

in HA management prior to consideration of MEI, and limited data on the

pool of ‘unmet need’, makes this number difficult to quantify. Sensitivity analysis suggests that if one per cent of the estimated pool of individuals with moderate or severe hearing loss elected to have MEI, the additional cost would be $2,291,787. These estimates are based on prevalence data of hearing loss in Australia and include a large portion of older Australians for whom an MEI would not be viable.

## Conclusions

### Safety

No comparative evidence reporting on the safety of MEI compared with CI or BAHA was available. RCT evidence based on defined patient populations would better inform on any safety differences between MEI and the comparator procedures. In the absence of comparative safety data, information on the absolute safety of MEI, BAHA and CI implantation were included in this report. Even with the limitations in inclusion criteria for BAHA and CI data, much more evidence in terms of absolute patient numbers was available for CI. This reflects the fact that MEI is in its infancy compared with other more established alternatives.

The safety data revealed a wide variability in outcomes owing to the surgical techniques used, the devices implanted and the sites of implantation. Further, there was variability in outcome reporting between studies which considered the same device.

Residual hearing loss after implantation was uniquely reported in MEI patients. Residual hearing loss was reported upon by most MEI studies, with 13 studies reporting that patients suffered significant declines in mean residual hearing loss after MEI implantation. Unlike the CI literature, the MEI literature included many patients with mild or moderate HL. In these patients, any further deterioration in hearing may be of greater clinical importance compared with losses in patients

with severe or profound HL. Patients with CHL did not report significantly worse residual hearing after implantation.

Expert clinical opinion endorsed by the Advisory Panel notes that certain adverse events are likely to be more commonly seen in children than in adults. Paediatric bone is softer than that of adults, and has a longer osseointegration time, and hence may be more susceptible to device loosening or damage. Additionally, children may be likely to sustain head trauma during rambunctious play. Children may also be less reliable at cleaning and maintaining their implant site. This may be especially important in the case of the BAHA.

Communication with the manufacturer of the VSB device (Med-EL) indicates that this MEI is not MRI safe at any Tesla level, and can be removed if necessary.

Due to the differences in devices and the surgical procedures associated with them, the adverse events differ between MEI and its comparators. Overall, absolute evidence from case series studies suggests that MEI appears to be as safe as CI and BAHA.

### Effectiveness

This report has been limited by the paucity of high-level evidence upon which to draw conclusions on the effectiveness of the MEI. Only one comparative study assessed the MEI versus the CI, and no comparative studies assessed the MEI versus the BAHA. Three additional included comparative studies used

comparators which were not of relevance to this report. The remaining studies included to assess effectiveness were all case series, and subject to bias. These studies displayed considerable variability regarding patient enrolment, study design and length of follow-up. Several studies assessed the MEI in patients who had a range of hearing severities, such as mild to severe, which made meaningful reporting difficult for these various severities.

The main outcome of interest was functional gain. Where reported, the gain provided by the MEI was usually of clinical significance (≥10 dB). Other effectiveness outcomes were varied and not uniformly reported across the studies. Where reported, quality of life and patient satisfaction outcomes showed improvements after MEI implantation or activation. Where reported, technical outcomes generally showed improvements after MEI implantation or activation but statistical analyses were generally not supplied.

**Effectiveness of the MEI vs the CI in patients with SNHL of undefined severity**

One comparative study was assessed (NHMRC level III). Regarding projected speech recognition in patients with severe hearing loss, MEI appears to be less effective than CI. Regarding projected PS65 score in patients with mild, moderate or severe hearing loss, MEI appears to be less effective than CI.

As only one comparative study was available to inform upon the relative effectiveness of the MEI compared with the BAHA and the CI, absolute effectiveness outcomes were collated for the MEI implantation alone from 29

level IV studies. Of these 29 studies, seven were retrospective while the remaining were prospective studies. The majority of the available studies assessed the MEI

in patients with SNHL. This is reflective of the anticipated Australian practice suggested by clinical experts. Sample sizes ranged from one to 125 patients; however, the majority of studies (22 out of 29) had less than 20 patients. In some studies it was not clearly stated whether baseline measures were measured with or without a HA.

**Effectiveness of the MEI in patients with mild or moderate SNHL**

Four studies were available with a total of 50 patients. These included two comparative studies reporting on internal comparisons between different types of MEI and two case series. In summary, MEI appears to be effective in improving hearing from baseline, pre-implantation levels in patients with mild or moderate SNHL.

**Effectiveness of the MEI in patients with severe SNHL**

One case series with a total of 13 patients was available for this indication. In summary, MEI appears to be effective in improving hearing from baseline, pre- implantation levels in patients with severe SNHL. Importantly, only a small number of patients were assessed and no statistical analyses were reported.

**Effectiveness of the MEI in patients with SNHL of undefined severity**

Nine case series with a total of 262 patients were available for this indication, and statistical analyses were rarely provided to substantiate effectiveness outcomes. In summary, MEI appears to improve hearing in patients with SNHL of undefined

severity. However, the data are of relatively low quality and outcome measures are variable between studies.

**Effectiveness of the MEI in patients with mild or moderate MHL**

Six case series with a total of 47 procedures in 46 patients were available for this indication. Two of the case series modified the MEI devices due to varied middle ear anatomy. In summary, generally MEI implantation or activation led to improvements in patients with mild or moderate MHL. Importantly, only a small number of patients were assessed and no statistical analyses were reported.

**Effectiveness of the MEI in patients with severe MHL**

Two case series which assessed a total of 47 patients were available for this indication. One case series modified the MEI devices due to varied middle ear anatomy. In summary, generally MEI implantation or activation led to improvements in patients with severe MHL. Importantly, only a small number of patients were assessed and few statistical analyses were reported.

**Effectiveness of the MEI in patients with MHL of undefined severity**

One case series with a total of 19 patients was available for this indication. This case series modified the MEI devices due to varied middle ear anatomy. In summary, generally MEI implantation led to improvements in patients with MHL of undefined severity. Importantly, only a small number of patients were assessed and few statistical analyses were reported.

**Effectiveness of the MEI in patients with CHL**

Two case series with a total of 12 patients who suffered from either unilateral osseous atresia or congenital auricular atresia were available for this indication. The implanted MEIs were modified to permit placement due to anatomic variation. In summary, 12 patients appeared to benefit from MEI implantation; however, this evidence is limited by the small number of patients studied and lack of statistical analysis. Additionally, these patients all suffered either unilateral osseous atresia or congenital auricular atresia, and it is unclear whether the benefits seen in these patients would extend to patients with other types of CHL.

The low level evidence suggests that in patients with mild, moderate or severe SNHL; SNHL of undefined severity; mild, moderate or severe MHL; MHL of undefined severity; or CHL; the MEI appears to be effective when implanted or switched on.

This report also briefly assessed the effectiveness of the MEI versus the external HA. Effectiveness outcomes were compromised by the fact that some studies reported that baseline measurements were taken with a digital, best fit, or state-of- the-art HA, while others used the patient’s own HA. It appears that presently

there is considerable variability in HA management prior to the consideration of MEI implantation. Generally the MEI appears to be as effective as the HA in patients with SNHL and MHL.

### Cost-effectiveness

The objective of the economic evaluation was to compare the cost-effectiveness

of MEI relative to BAHA and CI. In the absence of conclusive effectiveness data, a cost analysis was conducted to compare the different costs associated with each of the three procedures.

The estimated costs of MEI, BAHA and CI were taken from a number of sources. These included the Medicare Benefits Schedule (MBS), Australian Refined Diagnostic Related Group (AR-DRG) cost, manufacturer’s implants and the median charged MBS fee.

Based on a number of estimates and assumptions:

 The total estimated first year cost of an MEI, BAHA and CI is $23,873,

$15,207, and $34,466, respectively. The incremental cost of using an MEI as opposed to a BAHA is $8,666. The incremental cost saving of using an MEI as opposed to a CI is $10,593.

 Based on 2006-07 MBS data, the total cost of BAHA would be $1,611,957 (106 patients) and the total cost of CI would be $11,270,250 (327 patients). This gives a total cost of $12,882,207. If MEI was used instead of BAHA and CI the total cost would be $10,336,916. Hence the cost savings of performing MEI as a direct replacement for BAHA and CI would be over $2.5 million.

 Expert opinion endorsed by the Advisory Panel indicated that MEI would not just replace current CI and BAHA use, but would become another option in meeting the pool of unmet need of those with hearing loss. Expert opinion was that these individuals, currently persisting with hearing loss or a less than optimal hearing aid, may consider MEI implantation while they are not considering or accessing BAHA or CI. The previously mentioned variability in HA management prior to consideration of MEI, and limited data on the pool of ‘unmet need’, makes this number difficult to quantify. Sensitivity analysis suggests that if one per cent of the estimated pool of individuals with

moderate or severe hearing loss elected to have MEI, the additional cost would be $2,291,787. These estimates are based on prevalence data of hearing loss in Australia and include a large portion of older Australians for whom an MEI would not be viable.

## Appendix A

## MSAC terms of reference and membership

MSAC's terms of reference are to:

 advise the Minister for Health and Ageing on the strength of evidence pertaining to new and emerging medical technologies and procedures in relation to their safety, effectiveness and cost- effectiveness and under what circumstances public funding should be supported;

 advise the Minister for Health and Ageing on which new medical technologies and procedures should be funded on an interim basis to allow data to be assembled to determine their safety, effectiveness and cost-effectiveness;

 advise the Minister for Health and Ageing on references related either to new and/or existing medical technologies and procedures; and

 undertake health technology assessment work referred by the Australian Health Ministers’ Advisory Council (AHMAC) and report its findings to AHMAC.

The membership of MSAC comprises a mix of clinical expertise covering pathology, nuclear medicine, surgery, specialist medicine and general practice, plus clinical epidemiology and clinical trials, health economics, consumers, and health administration and planning:

**Member Expertise or Affiliation** Professor Robyn Ward (Chair) Medical Oncology Associate Professor Frederick Khafagi (Deputy Chair) Nuclear Medicine Professor Jim Butler (Economics Sub-committee Chair) Health Economics Associate Professor John Atherton Cardiology

Professor Justin Beilby General Practice/Research

Associate Professor Michael Bilous Anatomical Pathology

Professor Jim Bishop AO Chief Medical Officer (*ex officio member*) Professor Peter Cameron Trauma and Emergency Medicine Associate Professor Kirsty Douglas General Practice/Research

Dr Kwun Fong Thoracic Medicine

Professor Richard Fox Medical Oncology

Professor John Horvath Renal Medicine/Health Workforce

Ms Elizabeth Koff Health Administration Professor Helen Lapsley Health Economics Professor Peter McCluskey Ophthalmology

Mr Russell McGowan Consumer Health Representative

Dr Allan McKenzie Radiology

Dr Graeme Suthers Genetics/Pathology

Mr David Swan AHMAC Representative

Professor Ken Thomson Radiology

Dr Christine Tippett Obstetrics/Gynaecology Associate Professor David Winlaw Paediatric Cardiothoracic Surgery Dr Caroline Wright Colorectal Cancer/Surgery

Dr Shiong Tan Health Promotion/Population Health (resigned

24/02/2010)

## Appendix B

## Advisory panel and Evaluators

### Advisory panel for MSAC Application 1137: Middle ear implant for sensorineural, conductive and mixed hearing losses

**Dr Shiong Tan** Chair, member of MSAC (resigned 24/02/2010)

**A/Professor Kirsty Douglas**

*(Deputy Chair)*

Member of MSAC, member of Economics Sub- Committee

**A/Professor Melville Da Cruz** Royal Australasian College of Surgeons nominee

**Dr John Malouf** ENT specialist

**A/Professor Christopher Perry** ENT specialist

**Mr Jason Ridgway** Audiologist

**Ms Alexandra Rivers** Consumers’ Health Forum of Australia nominee

**Ms Hema Indrasamy** Project manager

### Economics Sub-Committee Advice to Advisory Panel

**Name Organisation**

**Professor Jim Butler**

MSAC member, Chair of Economics Sub- Committee

### Evaluators

**Name Organisation Mrs Caryn Perera** ASERNIP-S **Dr Prema Thavaneswaran** ASERNIP-S

**Mr Irving Lee** ASERNIP-S

**Dr Alun Cameron** ASERNIP-S

**Ms Jody Church** CHERE

**Dr Stephen Goodall** CHERE

## Appendix C

## Studies included in the Report

**Included comparative studies: CI vs MEI**

**SNHL**

Verhaegen VJO, Mylanus EAM, et al, 2008. ‘Audiological application criteria for implantable hearing aid devices: a clinical experience at the Nijmegen ORL clinic’, *The Laryngoscope*, 118, 1645-1649.

**MEI vs MEI SNHL**

Snik AFM, van Duijnhoven, et al, 2007. ‘Evaluation of the subjective effect of middle ear implantation in hearing-impaired patients with severe external otitis’, *Journal of the American Academy of Audiology,* 18, 496-503.

Snik A, Noten J, Cremers C, 2004. ‘Gain and maximum output of two electromagnetic middle ear implants: are real ear measurements helpful?’, *Journal of the American Academy of Audiology*, 15, 249-257.

Snik A and Cremers C, 2004a. ‘Audiometric evaluation of an attempt to optimize the fixation of the transducer of a middle-ear implant to the ossicular chain with bone cement’, *Clinical Otolaryngology and Allied Sciences,* 29, 5-9.

**Undefined hearing loss**

Stieve M, Winter M, et al, 2009. ‘The influence of the coupling of actuation drivers of implantable hearing systems on the mechanics of the middle ear’, *Cochlear Implants International*, 10, 160-165.

**MEI vs HA SNHL**

Chen DA, Backous DD, et al, 2004. ‘Phase 1 clinical trial results of the envoy system: a totally implantable middle ear device for sensorineural hearing loss’*, Otolaryngology - Head and Neck Surgery,* 131, 904-916.

Fraysse B, Lavieille J-P, et al, 2001. ‘A multicenter study of the Vibrant Soundbridge middle ear implant: early clinical results and experience’, *Otology and Neurotology*,

22, 952-961.

Hough JVD, Dyer RK, et al, 2001. ‘Early clinical results: SOUNDTEC implantable hearing device phase II study’, *The Laryngoscope,* 111, 1-8.

Jenkins HA, Atkins JS, et al, 2007. ‘US Phase I preliminary results of use of the Otologics MET fully-implantable ossicular stimulator’, *Otolaryngology - Head and Neck Surgery*, 137, 206-212.

Jenkins HA, Niparko JK, et al, 2004. ‘Otologics Middle Ear Transducer ossicular stimulator: performance results with varying degrees of sensorineural hearing loss’, *Acta Otolaryngologica*, 124, 391-394.

Luetje CM, Brackman D, et al, 2002. ‘Phase III clinical trial results with the Vibrant Soundbridge implantable middle ear hearing device: a prospective controlled multicenter study’, *Otolaryngology – Head and Neck Surgery*, 126, 97-107.

Matthews P, 2002. ‘The SOUNDTEC Direct System’, *Trends in Amplification*, 6, 61-65. Roland PS, Shoup AG, et al, 2001. ‘Verification of improved patient outcomes with a

partially implantable hearing aid, the SOUNDTEC Direct Hearing System’, *The*

*Laryngoscope*, 111, 1682-1686.

Snik AFM and Cremers CWRJ, 2001. ‘Vibrant semi-implantable hearing device with digital sound processing’, *Archives of Otolaryngology Head and Neck Surgery*, 127,

1433-1437.

Thill M-P, Gerard J-M, et al, 2002. ‘Belgian experience with the Vibrant Soundbridge prosthesis’, *Acta Oto-rhino-laryngologica Belgica*, 56, 375-378.

Todt I, Seidl RO, Ernst A., 2005. ‘Hearing benefit of patients after Vibrant Soundbridge implantation’, *ORL*, 67, 203-206.

Todt I, Seidl RO, et al, 2002. ‘Comparison of different Vibrant Soundbridge audioprocessors with conventional hearing aids’, *Otology and Neurotology*, 23, 669-

673.

Uziel A, Mondain M, et al, 2003. ‘Rehabilitation for high-frequency sensorineural hearing impairment in adults with the Symphonix Vibrant Soundbridge: a comparative study’, *Otology and Neurotology*, 24, 775-783.

Verhaegen VJO, Mylanus EAM, et al, 2008. ‘Audiological application criteria for implantable hearing aid devices: a clinical experience at the Nijmegen ORL clinic’, *The Laryngoscope*, 118, 1645-1649.

**Additional FDA cohort:**

Symphonix Devices, Incorporated. ‘Summary of safety and effectiveness’ available at:

<http://www.accessdata.fda.gov/cdrh_docs/pdf/P990052b.pdf>

**MHL**

Tos M, Salomon G, Bonding P, 1994. ‘Implantation of electromagnetic ossicular replacement device’, *ENT Journal*, 73, 92-103.

Caye-Thomasen P, Jensen JH, et al, 2002. ‘Long-term results and experience with the first-generation semi-implantable electromagnetic hearing aid with ossicular replacement device for mixed hearing loss’, *Otology and Neurotology*, 23, 904-911.

**CHL**

Nil

**UNDEFINED HEARING LOSS**

Kodera K, Suzuki J, et al, 1994. ‘Sound evaluation of partially implantable piezoelectric middle ear implant: comparative study of frequency response’, *ENT Journal*, 73,

108-111.

Schmuziger N, Schimmann F, et al, 2006. ‘Long-term assessment after implantation of the Vibrant Soundbridge device’, *Otology and Neurotology*, 27, 183-188.

Truy E, Philibert B, et al, 2008. ‘Vibrant Soundbridge versus conventional hearing aid in sensorineural high-frequency hearing loss: a prospective study’, *Otology and Neurotology*, 29, 684-687.

**Included MEI case series**

**SNHL case series**

Barbara M, Manni V, Monini S, 2009. ‘Totally implantable middle ear device for rehabilitation of sensorineural hearing loss: preliminary experience with the Esteem, Envoy’, *Acta Oto-Laryngologica*, 129, 429-432.

Cremers CWRJ, Verhaegen VJO, Snik AFM, 2008. ‘The floating mass transducer of the Vibrant Soundbridge interposed between the stapes and tympanic membrane after incus necrosis’, *Otology and Neurotology*, 30, 76-78.

Fisch U, Cremers CWRJ, et al, 2001. ‘Clinical experience with the Vibrant Soundbridge implant device’, *Otology and Neurotology*, 22, 962-972.

Foyt D and Carfrae M, 2006. ‘Minimal access surgery for the Symphonix/Med-El

Vibrant Soundbridge middle ear hearing implant’, *Otology and Neutotology*, 27, 167-

171.

Garin P, Thill MP, et al, 2002. ‘Speech discrimination in background noise with the

Vibrant Soundbridge middle ear implant’, *Oto Rhino Laryngologia Nova*, 12, 119-

123.

Snik AFM, van Duijnhoven NTL, et al, 2006. ‘Estimated cost-effectiveness of active middle-ear implantation in hearing-impaired patients with severe external otitis’, *Archives of Otolaryngology Head and Neck Surgery*, 132, 1210-1215.

Snik AFM and Cremers CWRJ, 2000. ‘The effect of the “floating mass transducer” in the middle ear on hearing sensitivity’, *The American Journal of Otology*, 21, 42-48.

Snik AFM and Cremers CWRJ, 1999. ‘First audiometric results with the Vibrant Soundbridge, a semi-implantable hearing device for sensorineural hearing loss’, *Audiology*, 38, 335-338.

Mosnier I, Sterkers O, et al, 2008. ‘Benefit of the Vibrant Soundbridge device in patients implanted for 5 to 8 years’, *Ear and Hearing*, 29, 281-284.

Sterkers O, Boucarra D, et al, 2003. ‘A middle ear implant, the Symphonix Vibrant Soundbridge: retrospective study of the first 125 patients implanted in France’, *Otology and Neurotology*, 24, 427-436.

Todt I, Seidl RO, et al, 2004. ‘MRI scanning and incus fixation in Vibrant Soundbridge implantation’, *Otology and Neurotology*, 25, 969-972.

Vincent C, Fraysse B, et al, 2004. ‘A longitudinal study on postoperative hearing thresholds with the Vibrant Soundbridge device’, *European Archives of Otorhinolaryngology*, 261, 492-496.

Zenner PH, Limberger A, et al, 2004. ‘Phase III results with a totally implantable piezoelectric middle ear implant: speech audiometry, spatial hearing and psychosocial adjustment’, *Acta Oto-Laryngologica*, 124, 155-164.

Zenner HP, Baumann JW, et al, 2003. ‘Patient selection for incus body coupling of a totally implantable middle ear implant’, *Acta Otolaryngologica*, 123, 683-696.

Zenner HP, 2000. ‘TICA totally implantable system for treatment of high-frequency sensorineural hearing loss’, *ENT Ear Nose and Throat*, 79, 770-777.

**MHL case series**

Colletti V, Carner M, Colletti L, 2009. ‘TORP vs round window implant for hearing restoration of patients with extensive ossicular chain defect’, *Acta Oto- Laryngologica*, 129, 449-452.

Colletti V, Soli SD, et al, 2006. ‘Treatment of mixed hearing losses via implantation of a vibratory transducer on the round window’, *International Journal of Audiology*, 45,

600-608.

Cuda D, Murri A, Tinelli N, 2009. ‘Piezoelectric round window osteoplasty for Vibrant

Soundbridge implant’, *Otology and Neurotology*, 30, 782-786.

Dumon T, Gratacap B, et al, 2009. ‘Vibrant Soundbridge middle ear implant in mixed hearing loss. Indications, techniques, results’, *Revue de Laryngologie-Otologie- Rhinologie*, 130, 75-81.

Dumon T, 2007. ‘Vibrant Soundbridge middle ear implant in otosclerosis: technique –

indication’, *Advances in Oto-rhino-laryngology*, 65, 320-322.

Foyt D and Carfrae M, 2006. ‘Minimal access surgery for the Symphonix/Med-El

Vibrant Soundbridge middle ear hearing implant’, *Otology and Neutotology*, 27, 167-

171.

Lefebvre PP, Martin C, et al, 2009. ‘A pilot study of the safety and performance of the Otologics fully implantable hearing device: transducing sounds via the round window membrane to the inner ear’, *Audiology and Neurotology*, 14, 172-180.

Streitberger C, Perotti M, et al, 2009. ‘Vibrant Soundbridge for hearing restoration after chronic ear surgery’, *Revue de Laryngologie-Otologie-Rhinologie*, 130, 83-88.

Suzuki J-I, Kodera K, et al, 1995. ‘Partially implantable piezoelectric middle ear hearing device: long term results’, *Otolaryngologic Clinics of North America*, 28, 99-107.

Suzuki J-I, Kodera K, et al, 1994. ‘Long-term clinical results of the partially implantable piezoelectric middle ear implant’, *ENT Journal*, 73, 104-107.

Suzuki JI, Kodera K, et al, 1989. ‘Further clinical experiences with middle-ear implantable hearing aids: indications and sound quality evaluation’, *ORL*, 51,

229-234.

Tono T, Inaba J, et al, 2000. ‘Clinical experience with partially implantable middle ear implant’, *Advances in Otorhinolaryngology*, 57, 186-188.

Tringali S, Pergola N, et al, 2009. ‘Fully implantable hearing device with transducer on the round window as a treatment of mixed hearing loss’, *Auris Nasus Larynx*, 36,

353-358.

Venail F, Lavieille JP, et al, 2007. ‘New perspectives for middle ear implants: first results in otosclerosis with mixed hearing loss’, *The Laryngoscope*, 117, 552-555.

Yanagihara N, Sato H, et al, 2001. ‘Long-term results using a piezoelectric semi- implantable middle ear hearing device’, *Otolaryngologic Clinics of North America*, 34,

389-400.

Yanagihara N, Hinohira Y, Gyo K, 1997. ‘Surgical rehabilitation of deafness with partially implantable hearing aid using piezoelectric ceramic bimorpli ossicular vibrator’, *Auris Nasus Larynx*, 24, 91-98.

**CHL case series**

Frenzel H, Hanke F, et al, 2009. ‘Application of the Vibrant Soundbridge to unilateral osseous atresia cases’, *The Laryngoscope*, 119, 76-74.

Siegert R, Mattheis S, Kasic J, 2007. ‘Fully implantable hearing aids in patients with congenital auricular atresia’, *The Laryngoscope*, 117, 336-340.

Tringali S, Pergola N, et al, 2008. ‘Fully implantable hearing device as a new treatment of conductive hearing loss in Franceschetti syndrome’, *International Journal of Pediatric Otorhinolaryngology*, 72, 513-517.

**Undefined case series**

Nil

**Included CI studies:**

Bibas A, Phillips S, et al, 2006. ‘Chronic suppurative otitis media following paediatric cochlear implantation’, *Cochlear Implants International*, 7, 167-178.

Biernath KR, Reefhuis J, et al, 2006. ‘Bacterial meningitis among children with cochlear implants beyond 24 months after implantation’, *Pediatrics*, 117, 284-289.

Brown KD, Connell SS, et al, 2009. ‘Incidence and indications for revision cochlear implant surgery in adults and children’, *The Laryngoscope*, 119, 152-157.

Cote M, Ferron P, et al, 2007. ‘Cochlear reimplantation: causes of failure, outcomes, and audiologic performance’, *The Laryngoscope*, 117, 1225-1235.

Cullen RD, Fayad JN, et al, 2008. ‘Revision cochlear implant surgery in children’, *Otology and Neurotology*, 29, 214-220.

Dodson KM, Maiberger PG, Sismanis A, 2007. ‘Intracranial complications of cochlear implantation’, *Otology and Neurotology*, 28, 459-462.

Hopfenspirger MT, Levine SC, Rimell FL, 2007. ‘Infectious complications in pediatric cochlear implants’, *The Laryngoscope*, 117, 1825-1829.

Lassaletta L, Castro A, et al, 2006. ‘Quality of life in postlingually deaf patients following cochlear implantation’, *European Archives of Otorhinolaryngology*, 263, 267-270.

Lin Y-S, Lee F-P, Peng S-C, 2006. ‘Complications in children with long-term cochlear implants’, *ORL*, 68, 237-242.

Lloyd S, Meerton L, et al, 2007. ‘Taste change following cochlear implantation’, *Cochlear*

*Implants International*, 8, 203-210.

Migirov L, Taitelbaum-Swead R, et al, 2007. ‘Revision surgeries in cochlear implant patients: a review of 45 patients’, *European Archives of Otorhinolaryngology*, 264, 3-7.

Migirov L, Muchnik C, et al, 2006. ‘Surgical and medical complications in paediatric cochlear implantation: a review of 300 cases’, *Cochlear Implants International*, 7,

194-201.

Ovesen T and Johansen LV, 2009. ‘Post-operative problems and complications in 313 consecutive cochlear implantations’, *The Journal of Laryngology and Otology*, 123,

492-496.

Postelmans JTF, Cleffken B, Stokroos RJ, 2007. ‘Post-operative complications of cochlear implantation in adults and children: five years’ experience in Maastricht’, *The Journal of Laryngology and Otology*, 121, 318-323.

Ramsden R, Rotteveel L, et al, 2007. ‘Cochlear implantation in otosclerotic deafness’,

*Advances in Otorhinolaryngology*, 65, 328-334.

Shoman N, Ngo R, et al, 2008. ‘Prevalence of new-onset vestibular symptoms following cochlear implantation’, *Journal of Otolaryngology – Head and Neck Surgery*, 37, 388-

394.

Stalfors J and Tjellstrom A, 2008. ‘Skin reactions after BAHA surgery: a comparison between the U-graft technique and the BAHA dermatome’, *Otology and Neurotology*, 29, 1109-1114.

Stratigouleas ED, Perry BP, et al, 2006. ‘Complication rate of minimally invasive cochlear implantation’, *Otolaryngology – Head and Neck Surgery*, 135, 383-386.

Taibah K, 2009. ‘The transmeatal approach: a new technique in cochlear and middle ear implants’, *Cochlear Implants International*, 10, 218-228.

Verhaegen VJO, Mylanus EAM, et al, 2008. ‘Audiological application criteria for implantable hearing aid devices: a clinical experience at the Nijmegen ORL clinic’, *The Laryngoscope*, 118, 1645-1649.

Viccaro M, Mancini P, et al, 2007. ‘Positional vertigo and cochlear implantation’, *Otology and Neurotology*, 28, 764-767.

Wootten CT, Backous DD, Haynes DS, 2006. ‘Management of cerebrospinal fluid leakage from cochleostomy during cochlear implant surgery’, *The Laryngoscope*,

116, 2055-2059.

**Included BAHA studies:**

Badran K, Arya AK, et al, 2009. ‘Long-term complications of bone-anchored hearing aids: a 14-year experience’, *The Journal of Laryngology and Otology*, 123, 170-176.

Davids T, Gordon KA, et al, 2007. ‘Bone-anchored hearing aids in infants and children younger than 5 years’, *Archives of Otolaryngology Head and Neck Surgery*, 133, 51-55.

Gillett D, Fairley JW, et al, 2006. ‘Bone-anchored hearing aids: results of the first eight years of a programme in a district general hospital, assessed by the Glasgow benefit inventory’, *The Journal of Laryngology and Otology*, 120, 537-542.

Lloyd S, Almeyda J, et al, 2007. ‘Updated surgical experience with bone-anchored hearing aids in children’, *The Journal of Laryngology and Otology*, 121, 826-831.

Tjellstrom A, Granstrom G, Odersjo M, 2007. ‘Survival rate of self-tapping implants of bone-anchored hearing aids’, *The Journal of Laryngology and Otology*, 121, 101-104.

Yuen H-W, Bodmer D, et al, 2009. ‘Management of single-sided deafness with the bone-anchored hearing aid’, *Otolaryngology – Head and Neck Surgery*, 141, 16-23.

## Appendix D

## Further data tables

#### Table 63 Validity characteristics of comparative studies included in the report

**Study ID HL**

**severity**

**Study design Sample size**

**Follow-up**

**Inclusion criteria**

**Exclusion criteria**

**Comments**

**Retrospective Prospective Enrolment Losses to follow- up**

**Cochlear implant compared with middle ear implant**

***Sensorineural hearing loss***

Verhaegen 2008 **-** 

202 MEI and HA: at least 2 months

CI: 12 months

– –

  –

**Middle ear implant compared with hearing aid**

***FDA regulatory document***

Symphonix Devices Incorporated

2000 (FDA regulatory document)

Moderate –

to severe

54 5 months post- surgery plus an additional 6 weeks to acclimatise to the Vibrant D

audio processor.

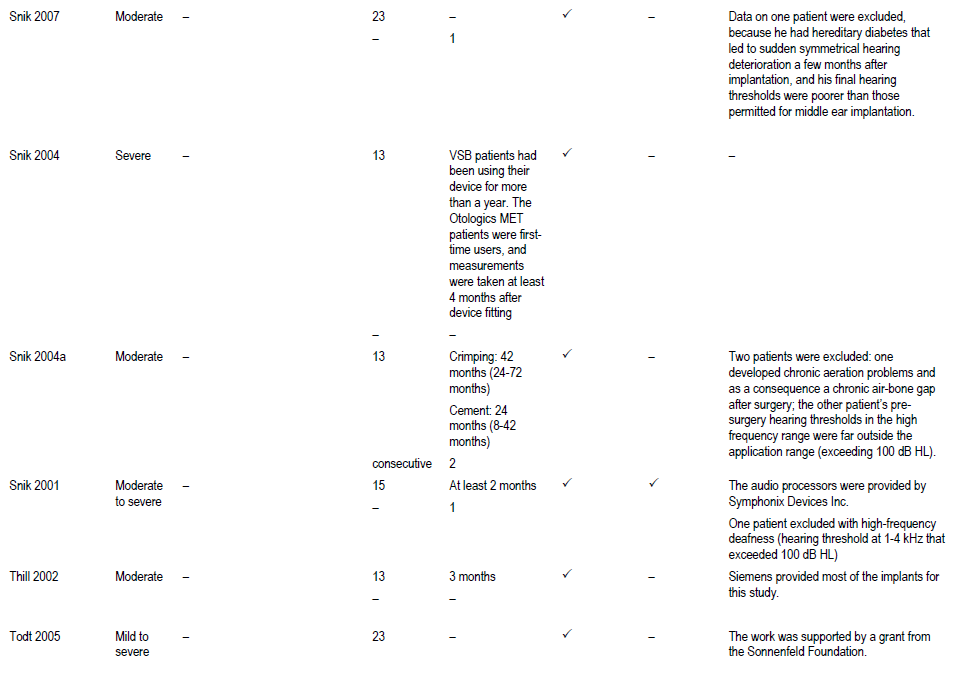
– 1

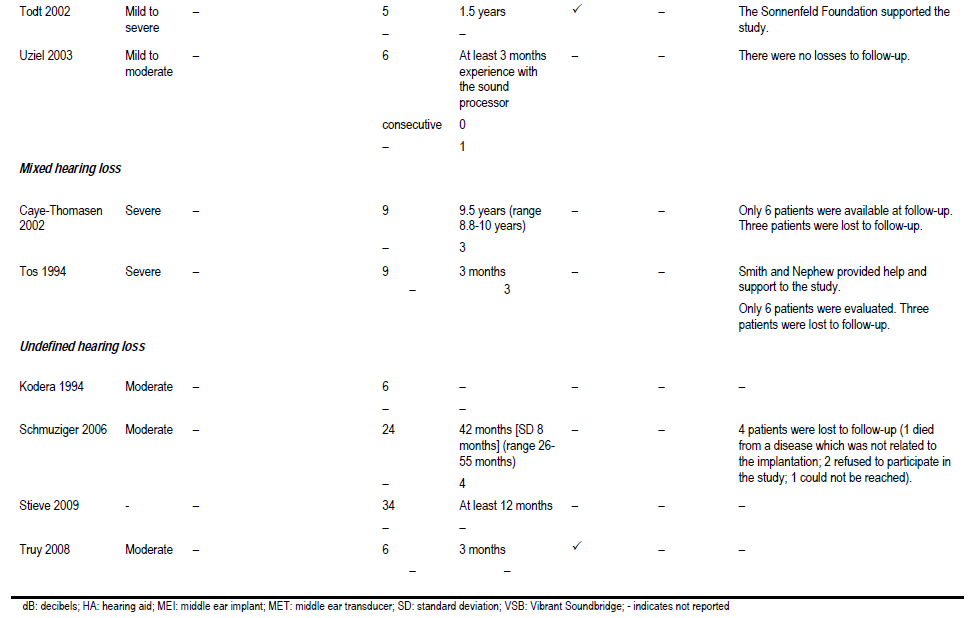
  This report was produced by the device manufacturer and the FDA.

|  |  |  |
| --- | --- | --- |
|  | | One patient’s device did not activate. This patient was not evaluated. |
|  |  | For safety outcomes, 5 subjects from the feasibility study and 22 subjects from the supplemental safety cohort were also assessed, in addition to the 54 patients in the clinical study. |

***Sensorineural hearing loss***







#### Table 64 Critical appraisal of case series for middle ear implant in patients with sensorineural hearing loss

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study ID** | **HL severity** | **Study** | **design** | **Sample size** | **Follow-up duration** | **Inclusion criteria** | **Exclusion criteria** | **Comments** |
|  |  | **Retro** | **Prosp** | **Enrolment** | **Losses** | **described** | **described** |  |
| Barbara 2009 | Moderate |  |  | 6 | - |  | - | - |
|  |  |  |  | Consecutive | - |  |  |  |
| Fisch 2001 | Mild to severe |  |  | 47 | 3 months |  |  | This study was supported by the manufacturer |
|  |  |  |  | - | - |  |  |  |
| Foyt 2006 | Moderate |  |  | 9 | 24 months | - | - | - |
|  |  |  |  | Consecutive | 1 |  |  |  |
| Garin 2002 | Moderate to severe |  |  | 9 | 15.6 months |  | - | - |
|  |  |  |  | - | - |  |  |  |
| Snik 2006 | - |  |  | 21 | 6 to 24 months | - | - | - |
|  |  |  |  | - | 4 |  |  |  |
| Snik 2000 | Moderate |  |  | 6 | 8 to 19 months |  | - | - |
|  |  |  |  | - | 0 |  |  |  |
| Snik 1999 | Moderate to severe |  |  | 7 | 2 months |  | - | Devices supplied by manufacturer |
|  |  |  |  | - | - |  |  |  |
| Sterkers 2003 | Mild to severe |  |  | 125 | 3 months |  | - | Contralateral hearing aid utilised |
| *Same cohort reported in Mosnier*  *2008* |  |  |  | Consecutive | 30 |  |  |  |
| Todt 2005 | - |  |  | 2 | - | - | - | Partly sponsored by Sonnenfield Foundation |
|  |  |  |  | - | 0 |  |  |  |
| Vincent 2004 | Moderate |  |  | 39 | 16 months |  | - | - |
|  |  |  |  | - | - |  |  |  |
| Zenner 2000 | Moderate to severe |  |  | 20 | 6 months |  | - | - |
|  |  |  |  | Consecutive | 1 |  |  |  |
| Zenner 2003 | Moderate to severe |  |  | 13 | Minimum 6 |  |  | - |

- months

-

Zenner 2004 Moderate to severe  20

-

6 months

1

  One patient was lost to follow-up (patient decided to leave the study prematurely)

- indicates not reported

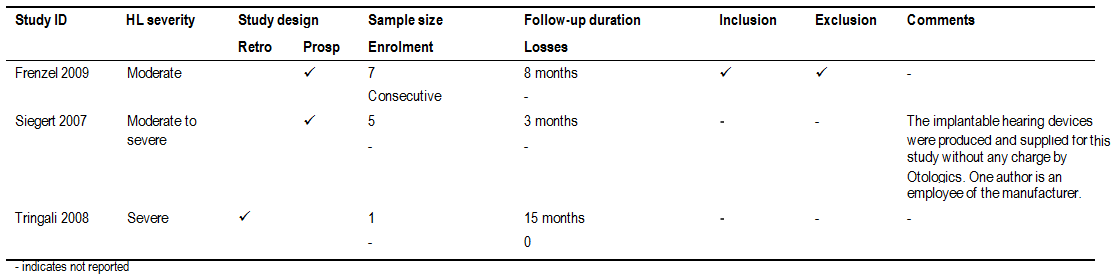
#### Table 65 Critical appraisal of case series for middle ear implant in patients with mixed hearing loss

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study ID** | **HL severity** | **Study**  **Retro** | **design**  **Prosp** | **Sample size**  **Enrolment** | **Follow-up duration**  **Losses** | **Inclusion** | **Exclusion** | **Comments** |
| Colletti 2009 | Moderate to severe |  |  | 19 | 36 months | - | - | Eardrops used for 4 weeks post implant |
|  |  |  |  | - | - |  |  |  |
| Colletti 2006 | Severe |  |  | 7 | 9 months | - | - | - |
|  |  |  |  | - | - |  |  |  |
| Cuda 2009 | Moderate |  |  | 8 | 12 months | - | - | - |
|  |  |  |  | - | 0 |  |  |  |
| Dumon 2009 | Moderate |  |  | 13 | 6 months |  | - | - |
|  |  |  |  | - | 0 |  |  |  |
| Dumon 2007 | Severe |  |  | 1 | - | - | - | - |
|  |  |  |  | - | 0 |  |  |  |
| Foyt 2006 | Moderate |  |  | 1 | MI: 24 months; TS:44.4 months | - | - | - |
|  |  |  |  | Consecutive | 1 |  |  |  |
| Lefebvre 2009 | Moderate |  |  | 6 | 12 months |  |  | 2 authors are employees of manufacturer |
|  |  |  |  | - | 0 |  |  |  |

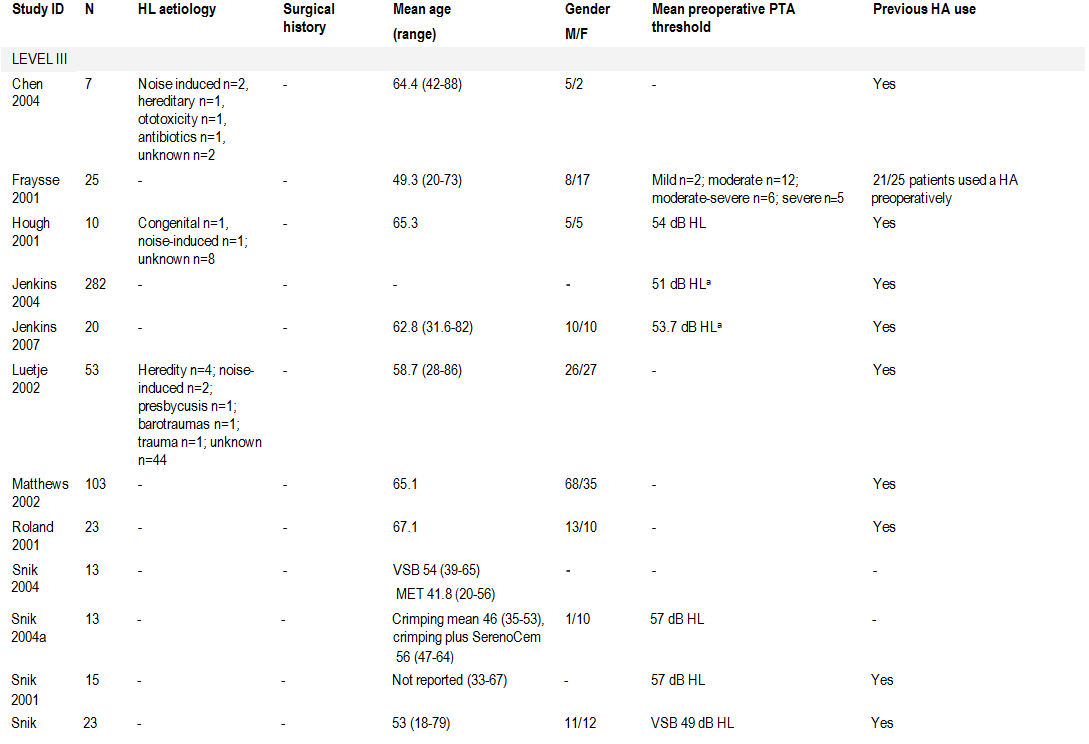
|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Streitberger 2009 | Severe |  |  | 40  - | 6 to 9 months  0 |  | - - |
| Suzuki 1989 | Moderate |  |  | 9 | - | - | - Contralateral hearing aid in 1 patient |
|  |  |  |  | - | 0 |  |  |
| Suzuki 1994 | - |  |  | 30 | 52 months | - | - Received some form of assistance from |
|  |  |  |  |  |  |  | an employee of manufacturer |
| *Same cohort reported in Suzuki* |  |  |  | - | - |  |  |
| *1995* |  |  |  |  |  |  |  |
| Tono 2000 | Moderate to |  |  | 3 | 24 to 48 months | - | - - |
|  | severe |  |  |  |  |  |  |
|  |  |  |  | - | 0 |  |  |
| Tringali 2009 | Severe |  |  | 1 | 15 months | - | - One author was employee of |
|  |  |  |  |  |  |  | manufacturer |
|  |  |  |  | - | 0 |  |  |
| Venail 2007 | Moderate to |  |  | 4 | - | - | - - |
|  | severe |  |  |  |  |  |  |
|  |  |  |  | - | 0 |  |  |
| Yanagihara 1997 | Moderate |  |  | 9 | 54 months | - | - - |
| *Same cohort reported in* |  |  |  | - | 1 |  |  |
| *Yanagihara 2001* |  |  |  |  |  |  |  |

MI: minimally invasive; TS: traditional surgery; - indicates not reported

#### Table 66 Critical appraisal of case series for middle ear implant in conductive hearing loss



#### Table 67 Patient characteristics for sensorineural hearing loss



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 2007  Thill | 13 | - | - | 57 (36-72) | 5/8 | MET 64 dB HL  - | Yes |
| 2002 |  |  |  |  |  |  |  |
| Todt  2002 | 5 | - | - | Not reported (54-69) | - | 55 dB HL | Yes |
| Todt  2005 | 23 | - | - | Not reported (41-80) | - | Mild to severe SNHL | Yes |
| Uziel  2003 | 6 | Noise-induced n=2, ototoxicity n=1; unknown n=3 | - | 56 (32-67) | 4/2 | 54.83 dB HL | Yes |
| LEVEL IV |  |  |  |  |  |  |  |
| Barbara  2009 | 6 | - | - | - | - | 58.9 dB HL | - |
| Cremers  2008 | 1 | Unknown | Prior VSB implanted, migrated into hypotympanum | 63 at original surgery | 0/1 | 55 dB HLa | Yes |
| Fisch | 47 | Unknown 40 (85%) | - | 48.4 (19-80) | 23/24 | Mild n=1 | Yesb |
| 2001 |  | Known 7 (15%) |  |  |  | Moderate n=24 |  |
|  |  |  |  |  |  | Moderate to severe n=18 |  |
|  |  |  |  |  |  | Severe n=4 |  |
| Foyt  2006 | 8 | - | - | Not reported (21-84) | 3/6 | 54.4 dB HL | Yes |
| Garin  2008 | 9 | Symmetric idiopathic bilateral SNHL | - | 63 (37-72) | 4/5 | Moderate to severe SNHL | Yes. All patients suffered from chronic eczema of the external auditory canal which led to repetitive bouts of otitis externa |
| Snik  1999 | 7 | - | - | 49.4 (33-67) | 2/5 | 56 dB HL | Yes. 5/7 stopped due to severe external otitis |
| Snik  2000 | 6 | - | No previous ear surgery | 49 (33-66) | 1/5 | 55 dB HL | No. All patients had severe bilateral chronic otitis externa, which made the use of ear moulds impossible or troublesome |
| Snik | 21 | - | - | 52.4 (18-79) | 9/12 | - | Yes |

2006

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sterkers  2003 | 125c | - | - 56 (24-81)c | 45/50c | Mild, moderate, moderate to severe, severe SNHL | 11/95 (11.5%) used HA before surgery |
| *Same cohort reported in Mosnier*  *2008* |  |  |  |  |  |  |
| Todt  2004 | 2 | 1 noise-induced, 1 unknown | - - | 2/0 | - | Yes |
| Vincent  2004 | 39 | - | - - | - | 54.6 dB HL | - |
| Zenner  2000 | 20 | - | - - | - | - | Yes |
| Zenner  2003 | 13 | - | - All adult (no further details) | - | Moderate to severe SNHL | 5 patients has used HAs and encountered problems, 8 patients could not use HA due to their professions |
| Zenner  2004 | 20 | - | - - | - | - | Yes |

a: Approximated and calculated from figure

b: For medical reasons, eight (17%) patients had been unable to use conventional amplification in the external ear before implantation. The remaining patients reported being dissatisfied with their hearing aids because of sound quality and/or discomfort and wanted to try a surgical solution for their hearing loss

c: Data only available for 95 patients

dB: decibels; HA: hearing aid; HL: hearing loss; MET: Otologics Middle Ear Transducer; PTA: pure-tone average; SNHL: sensorineural hearing loss; - indicates not reported

#### Table 68 Patient characteristics for mixed hearing loss

**Study ID N HL aetiology Surgical history Mean age**

**(range)**

LEVEL III

**Gender**

**M/F**

**Mean preoperative PTA thresholds**

**Previous HA use**

Tos 1994

*Same cohort reported in*

*Caye-Thomasen 2002*

LEVEL IV

9 Malleus fixation n=2;

absent stapes n=4

Previous conservative radical cavity n=2

Previous tympanoplasty n=1

60 (47-78) 3/3 - -

Colletti 2009 7 Chronic otitis media n=4; middle ear malformation/microtia/ atresia/stenosis n=1; tinnitus/vertigo n=1

1 previous surgery n=2

2 previous surgeries n=4

3 previous surgeries n=1

Surgeries included otoplasty, ossiculoplasty, tympanoplasty, MPL, 1 previous unsuccessful VSB implant on the incus

56.7 (28-74) 3/4 72.9 dB HL -

Colletti 2006 19 Bilateral chronic otitis media without cholesteatoma

- - 9/10 - -

Cuda 2009 8 Otosclerosis n=3, Cholesteatoma n=2, Tympanosclerosis n=2, Congenital aural atresia n=1

Previous stapes surgeries n=3

Tympanoplasty n=4

Atresia auris n=1

49.4 (28-59) 1/7 62.8 dB HL -

Dumon 2007 1 Primary otosclerosis - 42 1/0 - -

Dumon 2009 13 Otosclerosis n=5, Sequelae of chronic otitis n=7, Congenital aural atresia n=1

One otosclerosis patient had a stapedotomy piston implanted 37 years previously

56 (17-73) 7/6 - -

Foyt 2006 1 Ear canal stenosis and severe recurrent dermatitis

- Not reported

(21-84)

- 52 dB HL No: a HA could not be fitted

Lefebvre 2009 6 - - Adults (>18 years)

- - -

Streitberger 2009 40 Ossicular chain abnormal in all 40

All ears had previous surgeries (range 1-5 operations, median 3 operations). All had

59.5 (35-81) - - -

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | patients  Stapes footplate | tympanomastoidectomies (23 canal-wall up and 17 canal-wall down) |  | | | |
| abnormal in 20 patients |  |
| Suzuki 1989 | 9 (10 ears) | Chronic otitis media=  6 ears | One patient had a previous tympanoplasty | 55.8 (33-68) | 5/4 | - | - |
|  |  | Middle ear cholesteatoma= 3 ears |  |  |  |  |  |
|  |  | Microtia and atresia=  1 ear |  |  |  |  |  |
| Suzuki 1994 | 30 | - | One patient had preparatory operations | 58 (37-69) | 6/13 | - | - |
| *Same cohort reported in*  *Suzuki 1995* |  |  | (tympanoplasty in 1, not reported in other) |  |  |  |  |
| Tono 2000 | 3 | Cholesteatoma and otitis media with effusion n=1, Bilateral otitis media and tympanosclerosis n=1 | Tympanoplasty n=1, mastoidectomy n=3 | 55 (51-57) | 2/1 | - | One patient yes, not reported for 2 patients |
|  |  | Adhesive otitis media n=1 |  |  |  |  |  |
| Tringali 2009 | 1 | Bilateral hearing loss secondary to cholesteatoma | - | 48 | 0/1 | Mean 80 dB HL | Unclear. Patient did not want a standard HA for chronic irritation of the external ear canal |
| Venail 2008 | 4 | OM with labyrinthitis | Stapedotomy and Teflon piston n=2 | 59.5 (49-72) | 2/2 | - | Yes |
|  |  | n=1  Otosclerosis n=3 | Stapedotomy and McGee piston n=1 |  |  |  |  |
| Yanagihara 1997  *Same cohort reported in*  *Yanagihara 2001* | 9 | - | 3 patients had received MEI in the phase I study, but underwent reimplantation in the subsequent phase II study | 52 (42-67) | - | 67.1 dB HL | - |

dB: decibels; HA: hearing aid; HL hearing loss; MEI: middle ear implant; PTA: pure-tone average; - indicates not reported

#### Table 69 Patient characteristics for conductive hearing loss

**Study ID N HL aetiology Surgical history**

LEVEL IV

**Mean age**

**(range)**

**Gender**

**M/F**

**Mean preoperative PTA thresholds**

**Previous HA use**

Frenzel

2009

7 Unilateral microtia and osseous atresia - 15 (10-26) 5/2 69.2 dB HL Not reported (traditional hearing aids, worn externally in the ear canal, do not fit well in reconstructed ear canals)

Siegert

2007

Tringali

2008

5 Congenital auricular atresia n=5 (4 patients had unilateral and 1 patient had bilateral malformations)

1 Francheschetti syndrome (Treacher Collins).

Bilateral conductive hearing loss secondary to ossicular malformations and external ear agenesis

- 31.4 (18-40) 4/1 - -

- 14 1/0 70 dB HL Not reported (in Francheschetti syndrome with bilateral ear canal agenesis, conventional acoustic hearing aids cannot be used)

dB: decibels; HA: hearing aid; HL: hearing loss; PTA: pure-tone average; - indicates not reported

#### Table 70 Patient characteristics for undefined hearing loss

**Study ID N HL aetiology Surgical history**

LEVEL III

**Mean age**

**(range)**

**Gender**

**M/F**

**Mean preoperative PTA thresholds**

**Previous HA use**

Kodera 1994 6 - - - - 57 dB HL -

Schmuziger

2006

24a - - 59 (37-75) 16/4 - -

Stieve 2009 34 - - - - - -

Truy 2008 6 - - Not reported

(42-59)

2/4 - Yes

a: Four losses to follow-up

HA: hearing aid; HL: hearing loss; PTA: pure-tone average; - indicates not reported

#### Table 71 Technical characteristics for sensorineural hearing loss

**Study ID MEI Point of attachment**

**Attachment method Surgical technique Anaesthesia**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | **Access** | **Atticotomy** | **Mastoidectomy** | **Tympanotomy** | **Other details** |  |
| LEVEL III |  |  |  |  |  |  |  |  |
| Chen  2004 | Envoy | Lateral body of the incus and the tip of the capitulum of the stapes | Glass ionomeric cement | PAI | - |  | - | Incus resection | GA |
| Fraysse  2001 | VSB with D audio processor | Long process of the incus | FMT attachment clip | - | - |  |  | Enlarged endaural incision/simple retroauricular incision/enlarged retroauricular incision | GA |
| Hough  2001 | SOUNDTEC | Stapedial head | Incudostapedial joint opened, attachment ring placed | TC | - | - | - | Rosen canal excision, tympanomeatal flap elevated to visualise incudostapedial  joint. | LA |
| Jenkins  2004 | MET | Incus | 1 mm hole made in incus, healing leads to flexible fibrous union | PAI |  | - | - | - | - |

Jenkins

2007

MET Incus 0.75 mm hole made in incus

-  - - - GA

Luetje

2002

VSB with D audio processor

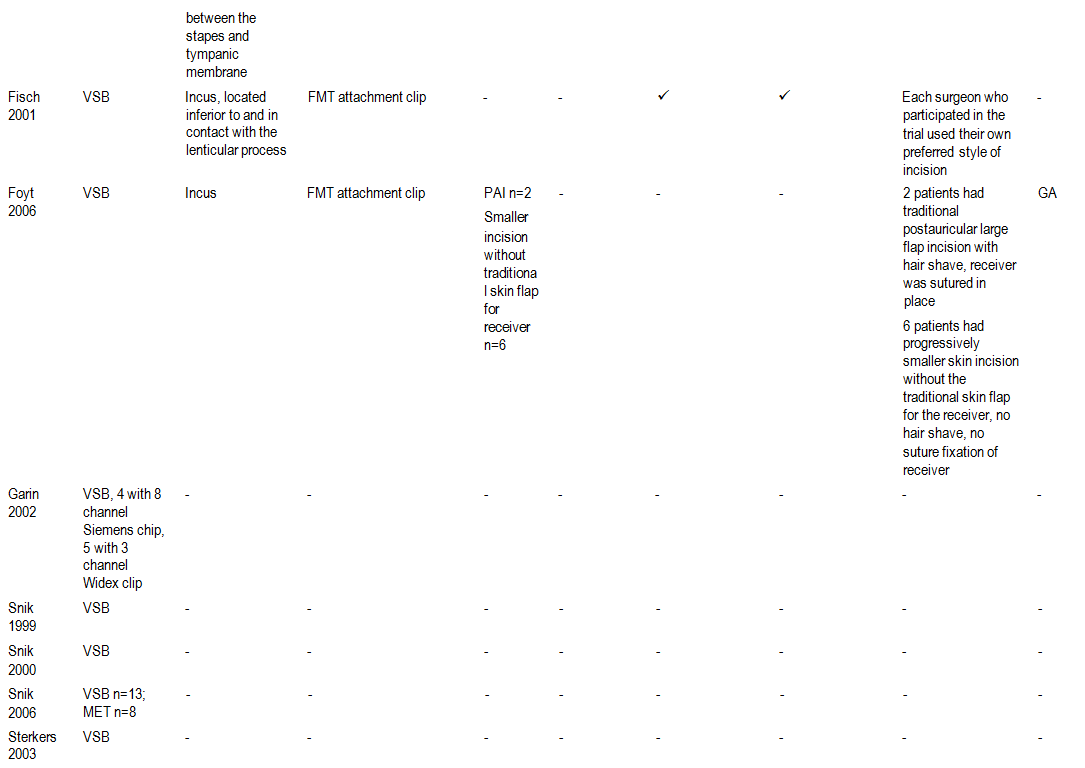
Incus FMT attached to incus (no further details provided)

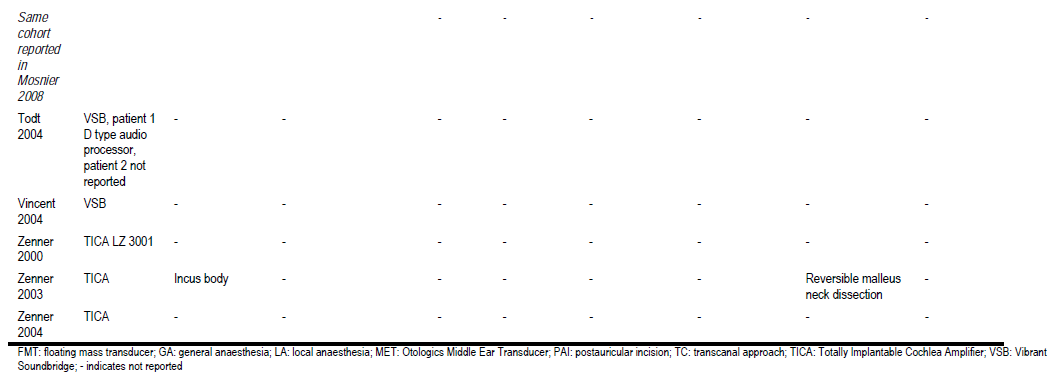
- - - - The surgical - approach is very

similar to that used for cochlear implantation

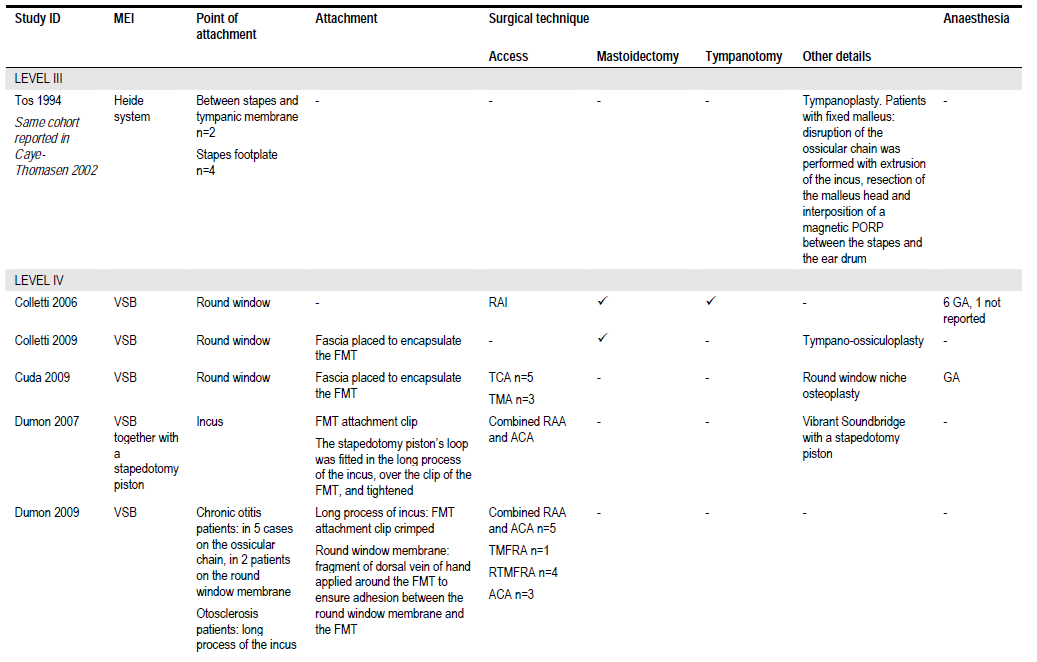
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Matthews | SOUNDTEC | Head of the | Incudostapedial joint | TC | - - - - - |
| 2002 |  | stapes | opened, attachment ring |  |  |
|  |  |  | placed, incudostapedial |  |  |
|  |  |  | joint closed |  |  |

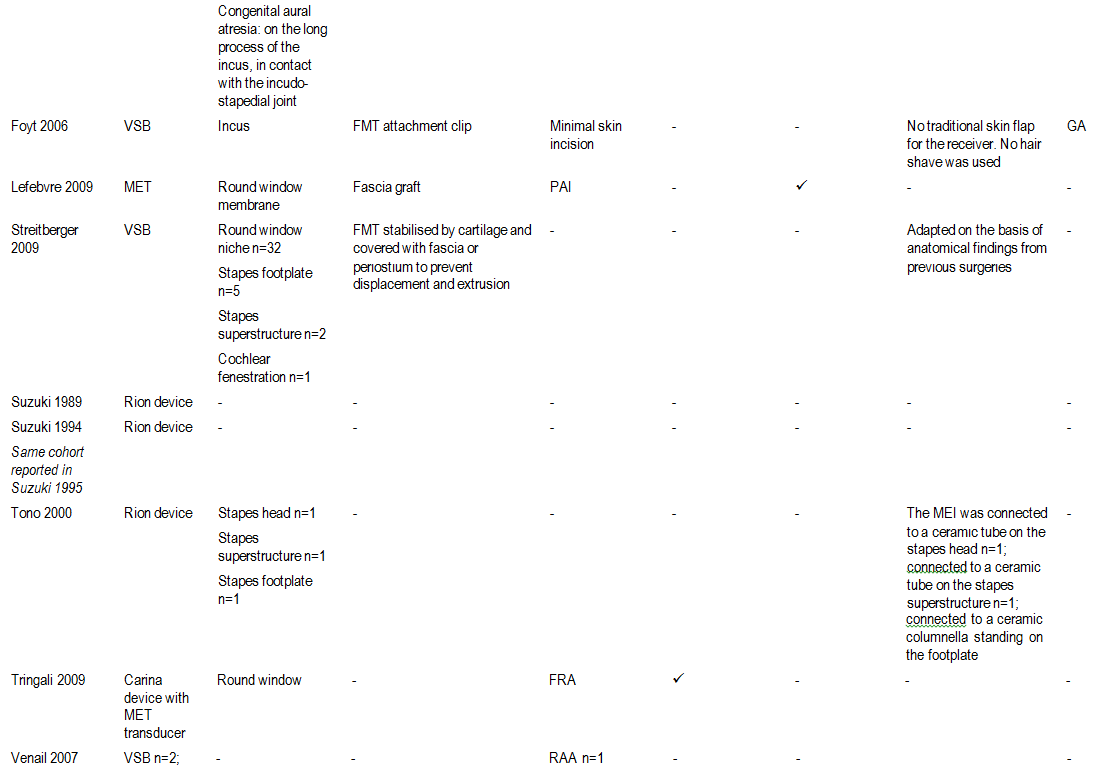
|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Roland  2001 | SOUNDTEC | Incudostapedial joint | - | - | - - | - | - | LA |
| Snik  2004 | VSB n=8; MET n=5 | - | - | - | - - | - | - | - |
| Snik  2004a | VSB with  304D audio processor | - | 6 attachment clip crimped,  7 patients attachment clip crimped and bone cement (SerenoCem) | - | - - | - | Each surgeon who participated in the trial used their own preferred style of incision | - |
| Snik  2001 | VSB | - | - | - | - - | - | - | - |
| Snik  2007 | VSB n=14; MET n=9 | - | - | - | - - | - | - | - |
| Thill 2002 | VSB | Incus | FMT attachment clip | - | -  |  | - | GA |
| Todt  2002 | VSB with D audio processor | Incus | Not reported (one patient had additional bone cement) | - | - - | - | Corresponds to cochlear implantations | - |
| Todt  2005 | VSB with Signia audio processor or D audio processor | - | - | - | - - | - | Similar to cochlear implantation but slightly modified (no further details) | - |
| Uziel  2003 | VSB | - | - | - | - - | - | - | - |
| LEVEL IV |  |  |  |  |  |  |  |  |
| Barbara  2009 | Esteem 2 | Sensor attached to body of incus, driver attached to head of stapes | Bioglass cement | PAI | -  |  | - | GA |
| Cremers  2008 | VSB | On top of the anterior crus, positioned | FMT’s grip was removed and SerenoCem used to affix | - | - - | - | - | - |





#### Table 72 Technical characteristics for mixed hearing loss





Yanagihara

1997

*Same cohort reported in Yanagihara*

*2001*

MET n=2 TCA n=2

- n=1

Rion device Stapes - - - - Type 1 operation: intact canal wall technique, thus preserving the posterior ear canal and the ear drum

Type 2 operation: device implantation into the ear missing the bony

external auditory canal

(most common)

LA with light sedation

ACA: auditory canal approach; FMT: floating mass transducer; FRA: facial recess approach; GA: general anaesthesia; LA: local anaesthesia; MEI: middle ear implant; MET: Otologics Middle Ear Transducer; TMA: transmastoid approach; TCA: transcanal approach; RAA: retroauricular approach; TMFRA: Trans-mastoid facial recess approach; RTMFRA: Retroauricular transmastoid facial recess approach; VSB: Vibrant Soundbridge; - indicates not reported

#### Table 73 Technical characteristics for conductive hearing loss

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study ID** | **MEI implanted** | **Point of attachment** | **Attachment type** | **Surgical technique** | **Anaesthesia** |
| LEVEL IV |  |  |  |  |  |
| Frenzel 2009 | VSB | Incus n=1 | Crimping (incus and footplate) | Implantation was performed as part of reconstructive surgery. | - |
|  |  | Round window n=2 | Fascia straps and cartilage chips (round window) | The incus and malleus were fused into a malformed complex |  |
|  |  | Stapes n=3 | Crimped and fascia strips (stapes) |  |  |
|  |  | Footplate n=1 |  |  |  |
| Siegert 2007 | MET | Stapes head | Prosthesis in pressure-free contact with stapes | Malleus-incus complex removed completely after severing the incudostapedial joint | - |
| Tringali 2008 | Carina device with MET V transducer | Posterior part of the oval window | - | Facial recess approach, posterior stapedotomy | - |

MEI: middle ear implant; MET: Otologics Middle Ear Transducer; - indicates not reported

#### Table 74 Technical characteristics for undefined hearing loss

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study ID** | **MEI implanted** | **Point of attachment** | **Attachment type** | **Surgical technique** | **Anaesthesia** |
| LEVEL III |  |  |  |  |  |
| Kodera 1994 | Rion device | - | - | - | - |
| Schmuziger  2006 | VSB | - | - | - | - |
| Stieve 2009 | MET n=19; VSB n=15 | MET: mastoid and incus | - | - | - |
|  |  | VSB: incus |  |  |  |
| Truy 2008 | VSB | - | - | - | - |

MEI: middle ear implant; MET: Otologics Middle Ear Transducer; VSB: Vibrant Soundbridge; - indicates not reported

## Appendix E

## Excluded studies

### Abstract/conference proceeding

Babighian G, Mazzoli M, 2005. ‘Implantable middle-ear implants: our experience’,

*Cochlear Implants International*, 6 Suppl 1, 65-69.

Baker KH, 2001. ‘Implantable middle ear hearing devices: a regulatory perspective’, *The*

*Hearing Journal*, 54, 36-37.

Beltrame MA, Cumer G, Frau GN, 2006. ‘Middle-ear implant transducer results of the coupling of the floating mass transducer (FMT) to the round window in patients with mixed hearing loss. Surgical technique and performance results’, *8th European Symposium on Pediatric Cochlear Implantation*, Venice, 2006.

Brazil C, Littman TA, Backous DD, 1999. ‘Assessment of the Vibrant Soundbridge auditory prosthesis’, *Otolaryngology Head and Neck Surgery*, 121, P231.

Colletti C, Carner M, Colletti L, 2006. ‘The bionic middle ear for the failures of ossiculoplasty’, *9th International Conference on Cochlear Implants and Related Science*, Vienna, June 2006.

Colletti V, Carner M, et al, 2005. ‘Round window stimulation with the Floating Mass Transducer: a new approach for surgical failures of mixed hearing losses’, *XVIII IFOS World Congress,* Rome, 25-30 June 2005.

Garin P, Debaty M, Galle C, 2005 ‘Hearing in noise with the Vibrant Soundbridge middle-ear implant’, *Cochlear Implants International*, 6 Suppl 1, 72-4.

Kelsall D, 2000. ‘Vibrant Soundbridge: U.S. clinical trial results’, *Laryngo-Rhino-Otologie*, 79

Suppl 1, S141.

Labassi S, Beliaeff M, 2005. ‘Retrospective of 1000 patients implanted with a Vibrant

Soundbridge middle-ear implant’, *Cochlear Implants International*, 6 Suppl 1, 74-77.

Mojallal H, Stieger C, et al, 2006. ‘DACS a new implantable hearing system for moderate to severe mixed hearing loss’, *IFMBE Proceedings*, 14, 3015-3017.

Winter M, Weber BP, Lenarz T, 2005. ‘The use of reverse transfer function (RTF) in the fitting procedure of implantable hearing devices’, *Cochlear Implants International*, 6

Suppl 1, 59-62.

Yanagihara N, Honda N, et al, 2004. ‘Piezoelectric semi-implantable middle-ear hearing device: Rion device E-type, long-term results’, *Cochlear Implants International*, 5

Suppl 1, 186-188.

### Animal study

Fredrickson JM, Coticchia JM, Khosla S, 1995. ‘Ongoing investigations into an implantable electromagnetic hearing aid for moderate to severe sensorineural hearing loss’, *Otolaryngologic Clinics of North America*, 28, 107-120.

Fredrickson JM, Tomlinson DR, et al, 1973. ‘Evaluation of an electromagnetic implantable hearing aid’, *Canadian Journal of Otolaryngology*, 2, 53-62.

Maniglia AJ, Dolgin SR, et al, 1988. ‘Electromagnetic implantable middle ear hearing device of the ossicular-stimulating type: principles, designs, and experiments’, *Transactions of the American Otological Society*, 76, 51-64.

Vernon J, Brummet R, et al, 1972. ‘Evaluation of an implantable type hearing aid by means of cochlear potentials’, *The Volta Review*, 1, 20-29.

Wei BPC, Shepherd RK, et al, 2007. ‘Threshold shift: effects of cochlear implantation on the risk of pneumococcal meningitis’, *Otolaryngology – Head and Neck Surgery*, 136,

589-596.

Wei MPC, Robins-Browne RM, et al, 2006. ‘Protective effects of local administration of ciprofloxacin on the risk of pneumococcal meningitis after cochlear implantation’, *The Laryngoscope*, 116, 2138-2144.

### Cadaver study

Abass HA, Kane M, 1997. ‘Mechanical, acoustic and electromagnetic evaluation of the semi-implantable middle ear hearing device (SIMEHD)’, *ENT: Ear, Nose and Throat Journal*, 76, 321-327.

Dumon T, Zennaro O, et al, 1995. ‘Piezoelectric middle ear implant preserving the ossicular chain’, *Otolaryngologic Clinics of North America*, 28, 173-187.

Dyer RK, Dormer KJ, et al, 2002. ‘Biomechanical influences of magnetic resonance imaging on the SOUNDTEC Direct System implant’, *Otolaryngology Head and Neck Surgery*, 127, 520-530.

Eiber M, Freitag H-G, et al, 1999. ‘Dynamics of middle ear prostheses – simulations and measurements’, *Audiology and Neutootology*, 4, 178-184.

Fayad JN, Eisenberg LS, et al, 2006. ‘Clinical performance of children following revision surgery for a cochlear implant’, *Otolaryngology – Head and Neck Surgery*, 134, 379-

384.

Gan RZ, Wood MW, 1997. ‘Implantable hearing device performance measured by laser

Doppler interferometry’, *ENT: Ear, Nose and Throat Journal*, 76, 297-299, 302,

305-309.

Goode RL, 1995. ‘Current status and future of implantable electromagnetic hearing aids’,

*Otolaryngologic Clinics of North America*, 28, 141-146.

Hunyadi S, Werning JW, et al, 1997. ‘Effect of magnetic resonance imaging on a new electromagnetic implantable middle ear hearing device’, *American Journal of Otology*,

18, 328-331.

Maniglia AJ, Murray G, et al, 2001. ‘Bioelectronic microphone options for a totally implantable hearing device for partial and total hearing loss’, *Otolaryngologic Clinics of North America*, 34, 469-483.

Maniglia AJ, Ko WH, 1994. ‘A contactless electromagnetic implantable middle ear device for sensorineural hearing loss’, *ENT Journal*, 73, 78-90.

Needham AJ, Jiang D, et al, 2005. ‘The effects of mass loading the ossicles with a

Floating Mass Transducer on middle ear transfer function’, *Otology and Neurotology*,

26, 218-224.

Roland PS, Wright CG, 2006. ‘Surgical aspects of cochlear implantation: mechanisms of insertional trauma’, *Advances in Otorhinolaryngology*, 64, 11-30.

Stakhovskaya O, Sridhar D, et al, 2007. ‘Frequency map for the human cochlear spiral ganglion: implications for cochlear implants’, *Journal of the Association for Research in Otolaryngology*, 8, 220-233.

Tohme SM, Karkas AA, Romanis BH, 2003. ‘Safety of MRI with metallic middle ear implants’, *Lebanese Medical Journal*, 51, 127-131.

Truy E, Eshraghi AA, et al, 2006. ‘Vibrant Soundbridge surgery: evaluation of transcanal surgical approaches’, *Otology and Neurotology*, 27, 887-895.

Winter M, Weber BP, Lenarz T, 2002. ‘Measurement method for the assessment of transmission properties of implantable hearing aids’, *Biomedizinische Technik*, 47

Suppl 1 Pt 2, 726-7.

### Duplicate reporting

Ashburn-Reed S, 2001. ‘The first FDA-approved middle ear implant: the Vibrant

Soundbridge’, *The Hearing Journal*, 54, 47-48.

Baker RS, Wood MW, Hough JVD, 1995. ‘The implantable hearing device for sensorineural hearing impairment’, *Otolaryngologic Clinics of North America*, 28, 147-

153.

Gyo K, Saiki T, Yanagihara N, 1996. ‘Implantable hearing aid using a piezoelectric ossicular vibrator: a speech audiometric study’, *Audiology*, 35, 271-276.

Kartush JM, Tos M, 1995. ‘Electromagnetic ossicular augmentation device’, *Otolaryngologic*

*Clinics of North America*, 28, 155-172.

### English abstract only

Dazert S, Shehata-Dieler WE, Dieler R, Helms J, 2000. ‘Soundbridge® middle ear implant for auditory rehabilitation in sensory hearing loss. Clinical aspects, indications and initial results’, *Laryngo-Rhino-Otologie*, 79, 459-464.

Lenarz T, Weber BP, Mack KF, et al, 1998. ‘Vibrant Soundbridge implant: a new hearing prosthesis for patients with sensorineural hearing loss; part 1 – principle of the Soundbridge system and initial clinical results’, *Laryngo-Rhino-Otologie*, 77, 247-255.

Lenarz T, Weber BP, Issing PR, et al, 2001. Vibrant Sound Bridge System. A new kind hearing prosthesis for patients with sensorineural hearing loss. 2. Audiological results’, *Laryngo-Rhino-Otologie*, 80, 370-380.

### Insufficient length of follow-up (comparators only)

Doshi J, Karagama Y, et al, 1984. ‘Observational study of bone-anchored hearing aid infection rates using different post-operative dressings’, *The Journal of Laryngology and Otology*, 120, 842-844.

Dumper D, Hodgetts, et al, 2009. ‘Indications for bone-anchored hearing aids: a functional outcomes study’, *Journal of Otolaryngology – Head and Neck Surgery*, 38,

96-105.

Enticott JC, Tari S, et al, 2006. ‘Cochlear implant and vestibular function’, *Otology and*

*Neurotology*, 27, 824-830.

Lin L-M, Bowditch S, et al, 2006. ‘Amplification in the rehabilitation of unilateral deafness: speech in noise and directional hearing effects with bone-anchored hearing and contralateral routing of signal amplification’, *Otology and Neurotology*,

27, 172-182.

### Insufficient patients included (comparators only)

Arenberg Bierer J, 2007. ‘Threshold and channel interaction in cochlear implant users: evaluation of the tripolar electrode configuration’, *Journal of the Acoustical Society of America*, 121, 1642-1653.

Bauer PW, Sharma A, et al, 2006. ‘Central auditory development in children with bilateral cochlear implants’, *Archives of Otolaryngology Head and Neck Surgery*, 132, 1133-1136.

Beijen J-W, Snik AFM, Mylanus EAM, 2007. ‘Sound localization ability of young children with bilateral cochlear implants’, *Otology and Neurotology*, 28, 479-485.

Boex C, Baud L, et al, 2006. ‘Acoustic to electric pitch comparisons in cochlear implant subjects with residual hearing’, *Journal of the Association for Research in Otolaryngology*,

7, 110-124.

Chatterjee M, Sarampalis A, Oba SI, 2006. ‘Auditory stream segregation with cochlear implants: a preliminary report’, *Hearing Research*, 222, 100-107.

Chatterjee M, Galvin JJ, et al, 2006. ‘Effects of stimulation mode, level and location on forward-masked excitation patterns in cochlear implant patients’, *Journal of the Association for Research in Otolaryngology*, 7, 15-25.

Cullington HE and Zeng F-G, 2008. ‘Speech recognition with varying numbers and types of competing talkers by normal-hearing, cochlear-implant, and implant

simulation subjects’, *Journal of the Acoustical Society of America*, 123, 450-461.

Damen GWJA, Pennings RJE, et al, 2006. ‘Quality of life and cochlear implantation in

Usher syndrome type I’, *The Laryngoscope*, 116, 723-728.

Firszt JB, Reeder RM, Skinner MW, 2008. ‘Restoring hearing symmetry with two cochlear implants or one cochlear implant and a contralateral hearing aid’, *Journal of Rehabilitation Research and Development*, 45, 749-768.

Fitzpatrick E, Durieux-Smith A, et al, 2006. ‘Economic evaluation of cochlear implants in children’, *Journal of Speech-Language Pathology and Audiology*, 30, 215-223.

Galvin JJ, Fu Q-J, Oba SI, 2009. ‘Effect of a competing instrument on melodic contour identification by cochlear implant users’, *Journal of the Acoustical Society of America*,

125, EL98-EL103.

Galvin JJ, Fu Q-J, Oba S, 2008. ‘Effect of instrument timbre on melodic contour identification by cochlear implant users’, *Journal of the Acoustical Society of America*,

124, EL189-EL195.

Hough JV, Vernon J, 1992. ‘Experiences with implantable hearing devices and a presentation of a new device’, *Seminars in Hearing*, 13, 275-282.

Hough J, Vernon J, et al, 1986. ‘Experiences with implantable hearing devices and a presentation of a new device’, *Annals of Otology, Rhinology and Laryngology*, 95, 60-

65.

Linstrom CJ, Silverman CA, Yu G-P, 2009. ‘Efficacy of the bone-anchored hearing aid for single-sided deafness’, *The Laryngoscope*, 119, 713-720.

Litovsky RY, Parkinson A, Arcaroli J, 2009. ‘Spatial hearing and speech intelligibility in bilateral cochlear implant users’, *Ear and Hearing*, 30, 419-431.

Loizou PC, Hu Y, et al, 2009. ‘Speech recognition by bilateral cochlear implant users in a cocktail-party setting’, *Journal of the Acoustical Society of America*, 125, 372-383.

Long CJ, Carlyon RP, et al, 2006. ‘Binaural unmasking with bilateral cochlear implants’,

*Journal of the Association for Research in Otolaryngology*, 7, 352-360.

Looi V, McDermott H, et al, 2008. ‘Music perception of cochlear implant users compared with that of hearing aid users’, *Ear and Hearing*, 29, 421-434.

Low W-K, Gopal K, et al, 2006. ‘Cochlear implantation in postirradiated ears: outcomes and challenges’, *The Laryngoscope*, 116, 1258-1262.

Luntz M, Brodsky A, et al, 2005. ‘Sound localization in patients with unilateral cochlear implants’, *Cochlear Implants International*, 6, 1-9.

Nava E, Bottari D, et al, 2009. ‘Spatial hearing with a single cochlear implant in late- implanted adults’, *Hearing Research*, 255, 91-98.

Neuman AC, Haravon A, et al, 2007. ‘Sound-direction identification with bilateral cochlear implants’, *Ear and Hearing*, 28, 73-82.

Nie K, Barco A, Zeng F-G, 2006. ‘Spectral and temporal cues in cochlear implant speech perception’, *Ear and Hearing*, 27, 208-217.

Pennings RJE, Damen GWJA, et al, 2006. ‘Audiologic performance and benefit of cochlear implantation in Usher syndrome type I’, *The Laryngoscope*, 116, 717-722.

Ricketts T, Grantham DW, et al, 2006. ‘Cochlear implant speech processor placement and compression effects on sound sensitivity and interaural level difference’, *Journal of the American Academy of Audiology*, 17, 133-140.

Ricketts TA, Grantham DW, et al, 2006. ‘Speech recognition for unilateral and bilateral cochlear implant modes in the presence of uncorrelated noise sources’, *Ear and Hearing*, 27, 763-773.

Sharma A, Dorman MF, 2006. ‘Central auditory development in children with cochlear implants: clinical implications’, *Advances in Otorhinolaryngology*, 64, 66-88.

Spriet A, Van Deun L, et al, 2007. ‘Speech understanding in background noise with the two-microphone adaptive beamformer BEAM™ in the Nucleus Freedom™ cochlear implant system’, *Ear and Hearing*, 28, 62-72.

Stickney GS, Assmann PF, et al, 2007. ‘Effects of cochlear implant processing and fundamental frequency on the intelligibility of competing sentences’, *Journal of the Acoustical Society of America*, 122, 1069-1078.

Tyler RS, Dunn CC, et al, 2007. ‘Speech perception and localization with adults with bilateral sequential cochlear implants’, *Ear and Hearing*, 28, 86S-90S.

Watson GJ, Silva S, et al, 2008. ‘Bone anchored hearing aids: a preliminary assessment of the impact on outpatients and cost when rehabilitating hearing in chronic suppurative otitis media’, *Clinical Otolaryngology*, 33, 338-342.

Wolfe J, Baker S, et al, 2007. ‘1-year postactivation results for sequentially implanted bilateral cochlear implant users’, *Otology and Neurotology*, 28, 589-596.

Yellon RF, 2007. ‘Bone anchored hearing aid in children – prevention of complications’,

*International Journal of Pediatric Otorhinolaryngology*, 71, 823-826.

### Letter

Glorig A, Moushegian G, et al, 1972. ‘Magnetically couples stimulation of the ossicular chain: measures in kangaroo rat and man’, *The Journal of the Acoustical Society of America*, 52, 694-696.

Zenner HP, Leysieffer H, 1998. ‘Totally implantable hearing device for sensorineural hearing loss’, *Lancet*, 352, 1751.

### Middle ear implant device development

Gyo K, et al, 1990. ‘Present status and outlook of the implantable hearing aid’, *The*

*American Journal of Otology*, 11, 250-253.

Gaverick, SL, Kane, M, 1997. ‘External unit for a semi-implantable middle ear hearing device’, *ENT: Ear, Nose and Throat Journal*, 76, 397-401.

Goode RL, 1970. ‘An implantable hearing aid: state of the art’, *Transactions of the American*

*Journal of Ophthalmology and Otology*, 74, 128-139.

Heide J, Tatge G, et al, 1988. ‘Development of a semi-implantable hearing device’,

*Advances in Audiology*, 4, 32-43.

Hough JVD, Dyer RK, et al, 2001. ‘Semi-implantable electromagnetic middle ear hearing device for moderate to severe sensorineural hearing loss’, *Otolaryngologic Clinics of North America*, 34, 401-416.

McGee TM, Kartush JM, et al, 1991. ‘Electromagnetic semi-implantable hearing device:

phase I. Clinical trials’, *Laryngoscope*, 101, 355-360.

Tjellstrom A and Luetje CM, 1997. ‘Acute human trial of the floating mass’, *ENT: Ear, Nose and Throat Journal*, 76, 204-206.

Yanagihara N, Gyo K, Hinohira Y, 1995. ‘Partially implantable hearing aid using piezoelectric ceramic ossicular vibrator: results of the implant operation and assessment of the hearing afforded by the device’, *Otolaryngologic Clinics of North America*, 28, 85-97.

Yanagihara N, Gyo K, et al, 1988. ‘Implantable hearing aid in fourteen patients with mixed deafness’, *Acta Otolaryngologica. Supplementum*, 458, 90-94.

Yanagihara N, Aritomo H, et al, 1987. ‘Implantable hearing aid: report of the first human applications’, *Archives of Otolaryngology Head and Neck Surgery*, 113, 869-872.

Yanagihara N, Yamanaka E, Gyo K, 1987. ‘Implantable hearing aid using an ossicular vibrator composed of a piezoelectric ceramic bimorph: application to four patients’, *The American Journal of Otology*, 8, 213-219.

Yanagihara N, Gyo K, et al, 1983. ‘Perception of sound through direct oscillation of the stapes using a piezoelectric ceramic bimorph’, *Annals of Otology, Rhinology and Laryngology*, 92, 223-227.

Yanagihara N, Suzuki j, et al, 1984. ‘Development of an implantable hearing aid using a piezoelectric vibrator of bimorph design: state of the art’, *Otolaryngology Head and Neck Surgery*, 92, 706-712.

Zenner HP, Leysieffer H, et al, 2000. ‘Human studies of a piezoelectric transducer and a microphone for a totally implantable electronic hearing device’, *The American Journal of Otology*, 21, 196-204.

### Middle ear implant device not implanted

Evans AK, Kazahaya K, 2007. ‘Canal atresia: “Surgery or implantable hearing devices?

The expert’s question is revisited”’, *International Journal of Pediatric*

*Otorhinolaryngology*, 71, 367-374.

Gates GA, Hough JV, et al, 1989. ‘The safety and effectiveness of an implanted electromagnetic hearing device’, *Archives of Otolaryngology Head and Neck Surgery*,

115, 924-930.

Goode RL, O’Keefe R, et al, 1986. ‘Clinical evaluation of a new nonelectronic all-in-the- ear hearing device for mild hearing loss’, *Otolaryngology Head and Neck Surgery*, 94,

343-350.

Goode RL, Glatkke TJ, 1973. ‘Audition via electromagnetic induction’, *Archives of*

*Otolaryngology*, 98, 23-26.

Gersdorff M, Garin P, Lurquin PH, 2002. ‘Implantable hearing aids vs classic hearing aids’, *Acta Oto-rhino-laryngologica Belgica*, 56, 363.

Hall JW and Derlacki EL, 1988. ‘Binaural hearing after middle ear surgery’, *Audiology*, 27,

89-98.

Hough J, Dormer KJ, et al, 1988. ‘Middle ear implantable hearing device: ongoing animal and human evaluation’, *Annals of Otology, Rhinology and Laryngology*, 97, 650-658.

Hopkinson NT, Bilger RC, Black FO, 1977. ‘Present audiological status of subjects implanted with auditory prostheses’, *Annals of Otology, Rhinology, Laryngology. Supplement*, 86, 40-48.

Junker R, Gross M, Todt I, et al, 2002. ‘Functional gain of already implanted hearing devices in patients with sensorineural hearing loss of varied origin and extent: Berlin experience’, *Otology and Neurotology*, 23, 452-456.

Kluk K and Moore BCJ, 2006. ‘Dead regions in the cochlea and enhancement of frequency discrimination: effects of audiogram slope, unilateral versus bilateral loss, and hearing-aid use’, *Hearing Research*, 222, 1-15.

Niehaus HH and Helms J, 1995. ‘Are implantable hearing devices really necessary?’,

*ENT: Ear, Nose and Throat Journal*, 74, 271-274, 276.

Newman CW and Sandridge SA, 1998. ‘Benefit from, satisfaction with, and cost- effectiveness of three different hearing aid technologies’, *American Journal of Audiology*, 7, 115-128.

Nin T, Sakagami M, Sone-Okunaka M, et al, 2006. ‘Taste function after section of chorda tympani nerve in middle ear surgery’, *Auris Nasus Larynx*, 33, 13-17.

Thelen A, Bauknecht H-C, et al, 2006. ‘Behavior of metal implants used in ENT surgery in 7 Tesla magnetic resonance imaging’, *European Archives of Otorhinolaryngology*,

263, 900-905.

Vega A, 1977. ‘Present neuropsychological status of subjects implanted with auditory prostheses’, *Annals of Otology, Rhinology and Laryngology. Supplement*, 86, 57-60.

Wild DC, Head K, Hall DA, 2006. ‘Safe magnetic resonance scanning of patients with metallic middle ear implants’, *Clinical Otolaryngology*, 31, 508-510

### No safety outcomes provided (comparators only)

Anderson HT, Schroder SA, Bonding P, 2006. ‘Unilateral deafness after acoustic neuroma surgery: subjective hearing handicap and the effect of the bone- anchored hearing aid’, *Otology and Neurotology*, 27, 809-814.

Badran K, Bunstone D, et al, 2006. ‘Patient satisfaction with the bone-anchored hearing aid: a 14-year experience’, *Otology and Neurotology*, 27, 659-666.

Briaire JJ, Frijns JHM, 2006. ‘The consequences of neural degeneration regarding optimal cochlear implant position in scala tympani: a model approach’, *Hearing Research*,

214, 17-27.

Carelsen B, Grolman W, et al, 2007. ‘Cochlear implant electrode array insertion monitoring with intra-operative 3D rotational X-ray’, *Clinical Otolaryngology*, 32,

42-59.

Filipo R, Mancini P, et al, 2008. ‘Assessment of intracochlear electrode position and correlation with behavioural thresholds in CII and 90K cochlear implants’, *Acta Oto-Laryngologica*, 128, 291-296.

Gantz BJ, Turner C, Gfeller KE, 2006. ‘Acoustic plus electric speech processing: preliminary results of a multicenter clinical trial of the Iowa/Nucleus hybrid implant’, *Audiology and Neurotology*, 11 Suppl 1, 63-68.

Kha HN, Chen BK, Clark GM, 2007. ‘3D finite element analyses of insertion of the Nucleus standard straight and the Contour electrode arrays into the human cochlea’, *Journal of Biomechanics*, 40, 2796-2805.

Litovsky R, Parkinson A, et al, 2006. ‘Simultaneous bilateral cochlear implantation in adults: a multicenter clinical study’, *Ear and Hearing*, 27, 714-731.

McDonald Connor C, Craig HK, et al, 2006. ‘The age at which young deaf children receive cochlear implants and their vocabulary and speech-production growth: is there an added value for early implantation?’, *Ear and Hearing*, 27, 628-644.

Morris LG, Mallur PS, et al, 2006. ‘Implication of central asymmetry in speech processing on selecting the ear for cochlear implantation’, *Otology and Neurotology*,

28, 25-30.

Nicholas JG and Geers AE, 2007. ‘Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss’, *Journal of Speech, Language, and Hearing Research*, 50, 1048-

1062.

Nicholas JG and Geers AE, 2006. ‘Effects of early auditory experience on the spoken language of deaf children at 3 years of age’, *Ear and Hearing*, 27, 286-298.

Paasche G, Bockel F, et al, 2006. ‘Changes of postoperative impedances in cochlear implant patients: the short-term effects of modified electrode surfaces and intracochlear corticosteroids’, *Otology and Neurotology*, 27, 639-647.

Quentin Summerfield A, Varton GR, et al, 2006. ‘Self-reported benefits from successive bilateral cochlear implantation in post-lingually deafened adults: randomised controlled trial’, *International Journal of Audiology*, 45 Suppl 1, S99-S107.

Roditi RE, Poissant SF, et al, 2009. ‘A predictive model of cochlear implant performance in postlingually deafened adults’, *Otology and Neurotology*, 30, 449-454.

Warner-Czyz AD, Loy B, et al, 2009. ‘Parent versus child assessment of quality of life in children using cochlear implants’, *International Journal of Pediatric Otorhinolaryngology*, Aug 10 [Epub ahead of print].

### Patients had not failed external hearing aid

Kiefer J, Arnold W, Staudenmaier R, 2006. ‘Round window stimulation with an implantable hearing aid (Soundbridge) combines with autogenous reconstruction of the auricle – a new approach’, *Cochlear Mechanics and Otoacoustic Emissions*, 68,

378-385.

Saliba I, Calmels M-N, et al, 2005. ‘Binaurality in middle ear implant recipients using contralateral digital hearing aids’, *Otology and Neurotology*, 26, 680-685.

### Patients were not consecutively enrolled (comparators only)

Ahn J H, Chung J W, Lee K-S, 2008. ‘Complications following cochlear implantation in patients with anomalous inner ears: experiences in Asan Medical Center’, *Acta Oto-Laryngologica*, 128, 38-42.

Anderson I, D’Haese P, Pitterl M, 2006. ‘Opinions of cochlear implant use in senior

Med-EL patients’, *ORL*, 68, 283-289.

Aschendorff A, Kromeier J, et al, 2007. ‘Quality control after insertion of the nucleus contour and contour advance electrode in adults’, *Ear and Hearing*, 28, 75S-79S.

Barton GR, Stacey PC, et al, 2006. ‘Hearing-impaired children in the United Kingdom, IV: cost-effectiveness of pediatric cochlear implantation’, *Ear and Hearing*, 27,

575-588.

Barton GR, Fortnum HM, et al, 2006. Hearing-impaired children in the United Kingdom, III: cochlear implantation and the economic costs incurred by families’, *Ear and Hearing*, 27, 563-574.

Berrettini S, Forli F, Passetti S, 2008. ‘Preservation of residual hearing following cochlear implantation: comparison between three surgical techniques’, *The Journal of Laryngology and Otology*, 122, 246-252.

Bonucci AS, Filho OAC, et al, 2008. ‘Vestibular function in cochlear implant users’,

*Brazilian Journal of Otorhinolaryngology*, 74, 273-278.

Buss E, Pillsbury HC, et al, 008. ‘Multicenter U.S. bilateral Med-EL cochlear implantation study: speech perception over the first year of use’, *Ear and Hearing*,

29, 20-32.

Connell SS, Balkany TJ, et al, 2008. ‘Electrode migration after cochlear implantation’,

*Otology and Neurotology*, 29, 156-159.

Crawford MW, White MC, et al, 2009. ‘Dose-dependent suppression of the electrically elicited stapedius reflex by general anesthetics in children undergoing cochlear implant surgery’, *Anesthesia and Analgesia*, 108, 1480-1487.

Di Nardo W, Cantore I, et al, 2007. ‘Tinnitus modifications after cochlear implantation’,

*European Archives of Otorhinolaryngology*, 264, 1145-1149.

Di Nardo W, Cantore I, et al, 2007. ‘Residual hearing in cochlear implant patients’,

*European Archives of Otorhinolaryngology*, 264, 855-860.

Di Nardo W, Cantore I, et al, 2007. ‘Residual hearing thresholds in cochlear implantation and reimplantation’, *Audiology and Neurotology*, 12, 165-169.

Donaldson GS, Chisolm TH, et al, 2009. ‘BLB-SIN and ANL predict perceived communication ability in cochlear implant users’, *Ear and Hearing*, 30, 401-410.

Eisenberg LS, Johnson KC, et al, 2006. ‘Speech recognition at 1-year follow-up in the Childhood Development after Cochlear Implantation study: methods and preliminary findings’, *Audiology and Neurotology*, 11, 259-268

Filipo R, Patrizi M, et al, 2006. ‘Vestibular impairment and cochlear implantation’, *Acta*

*Oto-Laryngologica*, 126, 1266-1274.

Francis HW, Buchman CA, et al, 2008. ‘Surgical factors in pediatric cochlear implantation and their early effects on electrode activation and functional outcomes’, *Otology and Neurotology*, 29, 502-508.

Fraysse B, Macias AR, et al, 2006. ‘Residual hearing conservation and electroacoustic stimulation with the Nucleus 24 contour advance cochlear implant’, *Otology and Neurotology*, 27, 624-633.

Galvin KL, Mok M, Dowell RC, 2007. ‘Perceptual benefit and functional outcomes for children using sequential bilateral cochlear implants’, *Ear and Hearing*, 28, 470-

482.

Gentile P, Bottini DJ, et al, 2008. ‘The use of bone-anchored implants for absent ear’,

*The Journal of Craniofacial Surgery*, 19, 744-747.

Gfeller KE, Olszewski C, et al, 2006. ‘Music perception with cochlear implants and residual hearing’, *Audiology and Neurotology*, 11 Suppl 1, 12-15.

Grantham DW, Ashmead DH, et al, 2007. ‘Horizontal-plane localization of noise and speech signals by postlingually deafened adults fitted with bilateral cochlear implants’, *Ear and Hearing*, 28, 524-541.

Grieco-Calub TM, Litovsky RY, Werner LA, 2008. ‘Using the observer-bases psychophysical procedure to assess localization acuity in toddlers who use bilateral cochlear implants’, *Otology and Neurotology*, 29, 235-239.

Jiang D, Bibas A, O’Connor AF, 2004. ‘Minimally invasive approach and fixation of cochlear and middle ear implants’, *Clinical Otolaryngology*, 29, 618-620.

Litovsky RY, Johnstone PM, Godar SP, 2006. ‘Benefits of bilateral cochlear implants and/or hearing aids in children’, *International Journal of Audiology*, 45 Suppl 1, S78- S91.

Litovsky RY, Johnstone PM, et al, 2006. ‘Bilateral cochlear implants in children:

localization acuity measured with minimum audible angle’, *Ear and Hearing*, 27,

43-59.

Nicholas JG, Geers AE, 2008. ‘Expected test scores for preschoolers with a cochlear implant who use spoken language’, *American Journal of Speech-Language Pathology*, 17,

121-138.

Noble W, Tyler R, et al, 2008. ‘Hearing handicap ratings among different profiles of adult cochlear implant users’, *Ear and Hearing*, 29, 112-120.

Noble W, Tyler R, et al, 2008. ‘Unilateral and bilateral cochlear implants and the implant- plus-hearing-aid profile: comparing self-assessed and measured abilities’, *International Journal of Audiology*, 47, 505-514.

Nott P, Cowan R, et al, 2009. ‘Early language development in children with profound hearing loss fitted with a device at a young age: part I – the time period taken to acquire first words and first word combinations’, *Ear and Hearing*, 30, 526-540.

Percy-Smith L, Caye-Thomasen P, et al, 2008. ‘Self-esteem and social well-being of children with cochlear implant compared to normal-hearing children’, *International Journal of Pediatric Otorhinolaryngology*, 72, 1113-1120.

Rama-Lopez J, Cervera-Paz FJ, Manrique M, 2006. ‘Cochlear implantation of patients with far-advanced otosclerosis’, *Otology and Neurotology*, 27, 153-158.

Reiss LAJ, Gantz BJ, Turner CW, 2008. ‘Cochlear implant speech processor frequency allocations may influence pitch perception’, *Otology and Neurotology*, 29, 160-167.

Reiss LAJ, Turner CW, et al, 2007. ‘Changes in pitch with a cochlear implant over time’,

*Journal of the Association for Research in Otolaryngology*, 8, 241-257.

Roeser MM, Driscoll CLW, et al, 2008. ‘Susac syndrome – a report of cochlear implantation and review of otologic manifestations in twenty-three patients’, *Otology and Neurotology*, 30, 34-40.

Sach TH and Barton GR, 2007. ‘Interpreting parental proxy reports of (health-related) quality of life for children with unilateral cochlear implants’, *International Journal of Pediatric Otorhinolaryngology*, 71, 435-445.

Sahli S and Belgin E, 2006. ‘Comparison of self-esteem level of adolescents with cochlear implant and normal hearing’, *International Journal of Pediatric Otorhinolaryngology*, 70,

1601-1608.

Scherf F, Van Deun L, et al, 2009. ‘Subjective benefits of sequential bilateral cochlear implantation in young children after 18 months of implant use’, *ORL*, 71, 112-

121.

Schorr EA, 2006. ‘Early cochlear implant experience and emotional functioning during childhood: loneliness in middle and late childhood’, *The Volta Review*, 106, 365-

379.

Schorr EA, Roth FP, Fox NA, 2009. ‘Quality of life for children with cochlear implants: perceived benefits and problems and the perception of single words and emotional sounds’, *Journal of Speech, Language, and Hearing Research*, 52, 141-152.

Stacey PC, Fortnum HM, et al, 2006. ‘Hearing-impaired children in the United Kingdom, I: auditory performance, communication skills, educational achievements, quality of life, and cochlear implantation’, *Ear and Hearing*, 27, 161-186.

Steffens T, Lesinski-Schiedat A, et al, 2008. ‘The benefits of sequential bilateral cochlear implantation for hearing-impaired children’, *Acta Oto-Laryngologica*, 128, 164-176.

Tjellstrom A and Granstrom G, 2006. ‘How we do it: frequency of skin necrosis after

BAHA surgery’, *Clinical Otolaryngology*, 31, 216-232.

Tonnaer EL, Mylanus EA, et al, 2009. ‘Detection of bacteria in healthy middle ears during cochlear implantation’, *Archives of Otolaryngology Head and Neck Surgery*, 135,

232-237.

Tringali S, Grayeli AB, et al, 2008. ‘A survey of satisfaction and use among patients fitted with a BAHA’, *European Archives of Otorhinolaryngology*, 265, 1461-1464.

Vermeire K, Brokx JPL, et al, 2005. ‘Good speech recognition and quality-of-life scores after cochlear implantation in patients with DFNA9’, *Otology and Neurotology*, 27,

44-49.

Zeitler DM, Kessler MA, et al, 2008. ‘Speech perception benefits of sequential bilateral cochlear implantation in children and adults: a retrospective analysis’, *Otology and Neurotology*, 29, 314-325.

### Potential duplication

Jenkins HA, Pergola N, Kasic J, 2007. ‘Intraoperative ossicular loading with the

Otologics fully implantable hearing device’, *Acta Oto-Laryngologica*, 127, 360-364.

Migirov L, Carmel E, Kronenberg J, 2008. ‘Cochlear implantation in infants: special surgical and medical aspects’, *The Laryngoscope*, 118, 2024-2027.

Migirov L, Yakirevitch A, et al, 2006. ‘Acute otitis media and mastoiditis following cochlear implantation’, *International Journal of Pediatric Otorhinolaryngology*, 70, 899-

903.

Migirov L, Yakirevitch A, Kronenberg J, 2006. ‘Surgical and medical complications following cochlear implantation: comparison of two surgical approaches’, *ORL*,

68, 213-219.

Migirov L, Amir A, Kronenberg J, 2006. ‘The influence of mastoidectomy on natural history of secretory otitis media in cochlear implant children’, *ORL* 2006, 68,

156-158.

Snik AFM, Mylanus EAM, et al, 2001. ‘Multicenter audiometric results with the Vibrant Soundbridge, a semi-implantable hearing device for sensorineural hearing impairment’, *Otolaryngologic Clinics of North America*, 34, 373-388.

Zenner HP, Leysieffer H, 2001. ‘Total implantation of the Implex TICA hearing amplifier implant for high-frequency sensorineural hearing loss’, *Otolaryngologic Clinics of North America*, 34, 417-446.

### Profound hearing loss outcomes

Anderson I, D’Haese PSC, Pitterl M, 2006. ‘Opinions on cochlear implant use in senior

Med-EL patients’, *ORL*, 68, 283-239.

Balkany T, Hodges A, et al, 2007. ‘Nucleus freedom North American clinical trial’,

*Otolaryngology – Head and Neck Surgery*, 136, 757-762.

Beltrame AM, Martini A, et al, 2009. ‘Coupling the Vibrant Soundbridge to cochlea round window: auditory results in patients with mixed hearing loss’, *Otology and Neurotology*, 30, 194-201.

Bichey BG and Miyamoto RT, 2008. ‘Outcomes in bilateral cochlear implantation’,

*Otolaryngology – Head and Neck Surgery*, 138, 655-661.

Black IM, Bailey CM, et al, 2007. ‘The Great Ormond Street Hospital paediatric cochlear implant programme 1992-2004: a review of surgical complications’, *Cochlear Implants International*, 8, 53-67.

Dettman SJ, Pinder D, et al, 2007. ‘Communication development in children who receive the cochlear implant younger than 12 months: risks versus benefits’, *Ear and Hearing*, 28, 11S-18S.

Kanchanalarp C, Cheewaruangroj W, et al, 2006. ‘Indication and surgical consideration

of cochlear implantation at Ramathibodi Hospital’, *Journal of the Medical Association of Thailand*, 89, 1171-1176.

Linder T, Schlegel C, et al, 2008. ‘Active middle ear implants in patients undergoing subtotal petrosectomy: new application for the Vibrant Soundbridge device and its implication for lateral cranium base surgery’, *Otology and Neurotology*, 30, 41-47.

Loundon N, Leboulanger N, et al, 2008. ‘Cochlear implant and inner ear malformation: proposal for an hypersmolar therapy at surgery’, *International Journal of Pediatric Otorhinolaryngology*, 72, 541-547.

Luo S-D, Su C-Y, et al, 2009. ‘Mastoid pressure dressing for cochlear implantation – is it necessary?’, *International Journal of Pediatric Otorhinolaryngology*, 73, 857-860.

Matterson AG, O’Leary S, et al, 2007. ‘Otosclerosis: selection of ear for cochlear implantation’, *Otology and Neurotology*, 28, 438-446.

Orabi AA, Mawman D, et al, 2006. ‘Cochlear implant outcomes and quality of life in the elderly: Manchester experience over 13 years’, *Clinical Otolaryngology*, 31, 116-122.

Peters BR, Litovsky R, et al, 2007. ‘Importance of age and postimplantation experience on speech perception measures in children with sequential bilateral cochlear implants’, *Otology and Neurotology*, 28, 649-657.

Yin S, Chen Z, et al, 2008. ‘Suprameatal approach for cochlear implantation in 45

Chinese children’, *International Journal of Pediatric Otorhinolaryngology*, 72, 397-403.

### Review/discussion – no clinical outcomes reported

Baker KH, 2001. ‘Implantable middle ear hearing devices: a regulatory perspective’,

*Hearing Journal*, 54, 36-37.

Cerini R, Faccioli N, et al, 2008. ‘Bionic ear imaging’, *La Radiologia Medica*, 113, 265-277. Chasin M and Spindel J, 2001. ‘Middle ear implants: a new technology’, *Hearing Journal*,

54, 33.

Ching TYC, van Wanrooy E, et al, 2006. ‘Performance in children with hearing aids or cochlear implants: bilateral stimulation and binaural hearing’, *International Journal of Audiology*, 45 Suppl 1, S108-S112.

Claes J and Van de Heyning, 2007. ‘Implantable electro-mechanical devices for sensorineural hearing loss’, *B ENT*, 3 Suppl 6, 51-58.

Discolo CM and Hirose K, 2002. ‘Pediatric cochlear implants’, *American Journal of*

*Audiology*, 11, 114-118.

Dormer KJ and Gan RZ, 2001. ‘Biomaterials for implantable middle ear hearing devices’,

*Otolaryngologic Clinics of North America*, 34, 289-297.

Foyt D, Steiniger E, Rende S, 2007. ‘Bone island tunnel for cochlear and vibrant soundbridge implantation’, *Laryngoscope*, 117, 1395-1396.

Goode RL, Rosenbaum ML, Maniglia AJ, 1995. ‘The history and development of the implantable hearing aid’, *Otolaryngologic Clinics of North America*, 28, 1-16.

Goode RL, 1988. ‘Electromagnetic implantable hearing aids’, *Advances in Audiology*, 4, 22-

31.

Grant IL, 2001. ‘MEI manufacturers describe their products’, *The Hearing Journal*, 54, 44-

48.

Gulya AJ, Stach B, 1996. ‘Hearing aids II. Implantable hearing aids’, *Archives of*

*Otolaryngology Head and Neck Surgery*, 122, 363-367.

Hiki S, Takahashi N, 1988. ‘Audiological evaluation of the middle ear implant’, *Advances in Audiology*, 4, 134-148.

Huttenbrink K-B, 2001. ‘Middle ear mechanics and their interface with respect to implantable electronic otologic devices’, *Otolaryngologic Clinics of North America*, 34,

315-335.

Huttenbrink K-B, 1999. ‘Current status and critical reflections on implantable hearing aids’, *American Journal of Otology*, 20, 409-415.

Jackler RK, 2006. ‘The impending end to the stigma of wearing ear devices and its revolutionary implications’, *Otology and Neurotology*, 27, 299-300.

Jaffee IS, 2001. ‘Implantable middle ear hearing devices’, *Otolaryngologic Clinics of North*

*America*, 34, 515-517.

Johr M, Ho A, et al, 2008. ‘Ear surgery in infants under one year of age: its risks and implications for cochlear implant surgery’, *Otology and Neurotology*, 29, 310-313.

Kasic JF and Fredrickson JM, 2001. ‘The Otologics MET ossicular stimulator’,

*Otolaryngologic Clinics of North America*, 34, 501-513.

Kartush JM, McGee TM, et al, 1991. ‘Electromagnetic semi-implantable hearing device:

an update’, *Otolaryngology Head and Neck Surgery*, 104, 150.

Kronenberg J and Migirov L, 2006. ‘The suprameatal approach: an alternative surgical technique for cochlear implantation’, *Cochlear Implants International*, 7, 142-147.

Maniglia AJ, 1996. ‘State of the art on the development of the implantable hearing device for partial hearing loss’, *Otolaryngologic Clinics of North America*, 29, 225-243.

Maniglia AJ, Ko WN, Garverick SL, et al, 1997. ‘Semi-implantable middle ear electromagnetic hearing device for sensorineural hearing loss’, *ENT: Ear, Nose and Throat Journal*, 76, 330-338, 340-341.

Marzo SJ, 2003. ‘Implantable hearing devices’, *ORL – Head and Neck Nursing*, 21, 22-25. Mills RP, 2001. ‘Middle ear hearing aid implants’, *Otorhinolaryngology, Head and Neck*

*Surgery*, 5, 8-9.

Raine CH, Martin J, 2001. ‘Cochlear and middle ear implants: advances for the hearing impaired’, *Hospital Medicine*, 62, 664-668.

Spindel JH, 2002. ‘Middle ear implantable hearing devices’, *American Journal of Audiology*,

11, 104-113.

Suzuki J-I, Shono H, Akiyama T, 1988. ‘Early studies and the history of development of the middle ear implant in Japan’, *Advances in Audiology*, 4, 1-14.

Suzuki J, Kodera K, Yanagihara N, 1985. ‘Middle ear implant for humans’, *Acta*

*Otolaryngologica,* 99, 313-317.

Suzuki J-I, 1983. ‘Various approaches for the improvement of hearing’, *Advances in Oto- rhino-laryngology*, 29, 194-198.

Tange RA, Grolman W, et al, 2009. ‘What to do with the other ear after cochlear implantation’, *Cochlear Implants International*, 10, 19-24.

Wood MW and Hough JVD, 2002. ‘Implantable hearing devices: contemporary options’,

*Current Opinion in Otolaryngology and Head and Neck Surgery*, 10, 350-354.

### Sudden sensorineural hearing loss

Kohan D, Morris LGT, Romo T, 2008. ‘Single-stage BAHA implantation in adults and children: is it safe?’, *Otolaryngology – Head and Neck Surgery*, 138, 662-666.

Mosnier I, Sterkers O, et al, 2009. ‘Speech performance and sound localization in a complex noisy environment in bilaterally implanted adult patients’, *Audiology and Neurotology*, 14, 106-114.

Shirazi MA, Marzo SJ, Leonetti JP, 2006. ‘Perioperative complications with the bone- anchored hearing aid’, *Otolaryngology – Head and Neck Surgery*, 134, 236-239.

### Unavailable via inter-library loan

Applebaum EL and Valvassori GE, 1990. ‘Further effects of the effects of magnetic resonance imaging fields on middle ear implants’, *Annals of Otology, Rhinology and Laryngology*, 99, 801-804.

Balkany TJ, Connell SS, et al, 2006. ‘Conservation of residual acoustic hearing after cochlear implantation’, *Otology and Neurotology*, 27, 1083-1088.

Brazil C, Littman TA, Backous DD, 1999. ‘Assessment of the Vibrant Soundbridge auditory prosthesis’, *Otolaryngology Head and Neck Surgery*, 121, 231.

Fredrickson J, 2001. ‘The Otologics MET ossicular stimulator’, *Hearing Journal*, 54, 46-47. Hawkins S, 2001. ‘“Direct” system can be implanted in an hour’, *Hearing Journal*, 54, 45. Hough JVD, Matthews P, et al, 2002. ‘Middle ear electromagnetic semi-implantable

hearing device: results of the phase II SOUNDTEC Direct System clinical trial’,

*Otology and Neurotology*, 23, 895-903

Hough J, Himelick T, et al, 1987. ‘A middle ear implantable hearing device for controlled amplification of sound in the human: a preliminary report’, *Laryngoscope*, 97, 141-

151.

Hough JV, Vernon J, Johnson B, 1986. ‘Experiences with implantable hearing devices and presentation of a new device’, *Annals of Otology, Rhinology and Laryngology*, 95,

60-65.

House JW, Kutz JW, 2007. ‘Bone-anchored hearing aids: incidence and management of postoperative complications’, *Otology and Neurotology’*, 28, 213-217.

Jenkins HA, Atkins JS, et al, 2008. ‘Otologics fully implantable hearing system: phase I

trial 1-year results’, *Otology and Neurotology*, 29, 534-541.

Junker R, Gross M, et al, 2002. ‘Evaluation of implantable hearing devices in patients

with sensorineural hearing loss of varied origin and extent’, *Otology and Neurotology*,

23, 452-456.

Lefebvre P et al, 2006. ‘Otologics fully implantable hearing device results’, *Wiener*

*Medizinische Wochenschrift*, 156, 84.

Lenarz T, Weber BP, et al, 1998. ‘Vibrant Soundbridge system. A new kind of hearing aid for sensorineural hearing loss. 1: Function and initial clinical experiences’, *Laryngorhinootologie*, 77, 247-255.

Loizou PC, Hu Y, et al, 2009. ‘Speech recognition by bilateral cochlear implant users in a cocktail-party setting’, *Journal of the Acoustical Society of America*, 125, 372-383.

Maniglia AJ, Ko WH, et al, 1994. ‘A contactless electromagnetic implantable middle ear device for sensorineural hearing loss’, *Ear, Nose and Throat Journal*, 73, 78-90.

Maniglia AJ, Ko WH, et al, 1988. ‘Electromagnetic implantable middle ear hearing device of the ossicular-stimulating type: principles, designs, and experiments’, *Annals of Otology, Rhinology and Laryngology. Supplement*, 136, 3-16.

Niehaus HH, Helms J, Muller J, 1995. ‘Are implantable hearing devices really necessary?’,

*Ear, Nose and Throat Journal*, 74, 271-276.

Saiki T, Gyo K, Yanagihara N, 1990. ‘Audiological evaluation of the middle ear implant –

temporal auditory acuity’, *Journal of Otolaryngology Japan*, 93, 413-419.

Silverstein H, Atkins J, et al, 2005. ‘Experience with the SoundTec implantable hearing aid’, *Otology and Neurotology*, 26, 211-217.

Spindel JH, Lambert PR, Ruth RA, 1995. ‘The round window electromagnetic implantable hearing aid approach’, *Otolaryngologic Clinics of North America*, 28, 189-

205.

Suzuki J-I, Kodera K, et al, 1995. ‘Partially implantable piezoelectric middle ear hearing device. Long-term results’, *Otolaryngologic Clinics of North America*, 28, 99-106.

Suzuki J-I, Kodera K, et al, 1989. ‘Further clinical experiences with middle-ear implantable hearing aids’, *ORL*, 51, 229-234.

Suzuki J et al, 1988. ‘Principle, construction and indication of the middle ear implant’,

*Advances in Audiology*, 4, 15-21.

Suzuki J et al, 1988. ‘Implantation of partially implantable middle ear implant and the indication’, *Advances in Audiology*, 4, 160-169.

Suzuki J et al, 1988. ‘Early studies and the history of development of the middle ear implant in Japan’, *Advances in Audiology*, 4, 1-14.

Tono T, Junko I, et al, 1999. ‘Clinical experiences and postoperative results with partially implantable middle ear implant’, *Journal of Otolaryngology Japan*, 102, 835-845.

Yanagihara N, et al, 1992. ‘Surgical aspects of the partially implantable hearing aid of the

Ehime type’, *Otolaryngology Head and Neck Surgery*, 3, 32-38.

Yanagihara N, Aritomo H, et al, 1988. ‘Intraoperative assessment of vibrator-induced hearing’, *Advances in Audiology*, 4, 124-13.

Yanagihara N et al, 1988. ‘Efficacy of the partially implantable middle ear implant in middle and inner ear disorders’, *Advances in Audiology*, 4, 149-159.

## Appendix F

## Clinical trials and health technology assessments

### Clinical trials

**Recruiting**

**Title:** Evaluation of middle ear implants in the therapeutic strategy of auditory rehabilitation in case of failure of conventional hearing aid

**Institution:** Assistance Publique – Hôspitaux de Paris

**Contact:** Oliver Sterkers

**Start date:** March 2007

**Expected completion date:** March 2011

**Identifier:** NCT00451503

## Appendix G

## Current MBS listings for hearing loss procedures

#### Table 75 Surgical approaches to hearing loss

**MBS item number**

**Therapeutic procedure**

10952 **AUDIOLOGY**

Audiology health service provided to a person by an eligible audiologist if:

(a) the service is provided to a person who has a chronic condition and complex care needs being managed by a medical practitioner (including a general practitioner, but not a specialist or consultant physician) under an EPC plan; and

(b) the service is recommended in the person's EPC plan as part of the management of the person's chronic condition and complex care needs; and

(c) the person is referred to the eligible audiologist by the medical practitioner using a referral form that has been issued by the Department or a referral form that substantially complies with the form issued by the Department; and

(d) the person is not an admitted patient of a hospital; and

(e) the service is provided to the person individually and in person; and

(f) the service is of at least 20 minutes duration; and

(g) after the service, the eligible audiologist gives a written report to the referring medical practitioner mentioned in paragraph (c):

(i) if the service is the only service under the referral - in relation to that service; or

(ii) if the service is the first or the last service under the referral - in relation to that service; or

(iii) if neither subparagraph (i) nor (ii) applies but the service involves matters that the referring medical practitioner would reasonably expect to be informed of - in relation to those matters; and

(h) for a service for which a private health insurance benefit is payable - the person who incurred the medical expenses for the service has elected to claim the Medicare benefit for the service, and not the private health insurance benefit;

- to a maximum of 5 services (including any services to which items 10950 to 10970 apply) in a calendar year

**Fee:** $57.55 **Benefit:** 85% = $48.95

T8.75 Reconstruction of Auditory Canal

When associated with Item 41557, 41560 or 41563 the multiple operation rule applies

20120 INITIATION OF MANAGEMENT OF ANAESTHESIA for procedures on external, middle or inner ear, including biopsy, not being a service to which another item in this Subgroup applies (5 basic units)

**Fee:** $91.50 **Benefit**: 75% = $68.65 85% = $77.80

41509 EXTERNAL AUDITORY MEATUS, surgical removal of keratosis obturans from, not being a service to which another item in this Group applies (Anaes.)

**Fee:** $150.55 **Benefit:** 75% = $112.95 85% = $128.00

41518 EXTERNAL AUDITORY MEATUS, removal of EXOSTOSES IN (Anaes.) (Assist.)

**Fee:** $858.05 **Benefit:** 75% = $643.55

41521 Correction of AUDITORY CANAL STENOSIS, including meatoplasty, with or without grafting

(Anaes.) (Assist.)

**Fee:** $913.55 **Benefit:** 75% = $685.20

41524 RECONSTRUCTION OF EXTERNAL AUDITORY CANAL, being a service associated with a service to which items 41557, 41560 and 41563 apply (Anaes.) (Assist.)

**Fee:** $263.95 **Benefit:** 75% = $198.00

41527 MYRINGOPLASTY, transcanal approach (Rosen incision) (Anaes.) (Assist.)

**Fee:** $542.85 **Benefit:** 75% = $407.15

41530 MYRINGOPLASTY, postaural or endaural approach with or without mastoid inspection (Anaes.)

**Fee:** $884.40 **Benefit:** 75% = $663.30

41533 ATTICOTOMY without reconstruction of the bony defect, with or without myringoplasty (Anaes.) (Assist.)

**Fee:** $1,057.20 **Benefit:** 75% = $792.90

41536 ATTICOTOMY with reconstruction of the bony defect, with or without myringoplasty (Anaes.) (Assist.)

**Fee:** $1,184.10 **Benefit:** 75% = $888.10

41539 OSSICULAR CHAIN RECONSTRUCTION (Anaes.) (Assist.)

**Fee:** $1,006.95 **Benefit:** 75% = $755.25

41542 OSSICULAR CHAIN RECONSTRUCTION AND MYRINGOPLASTY (Anaes.) (Assist.)

**Fee:** $1,103.30 **Benefit:** 75% = $827.50

41554 MASTOIDECTOMY, intact wall technique, with myringoplasty and ossicular chain reconstruction

(Anaes.) (Assist.)

**Fee:** $1,734.00 **Benefit:** 75% = $1,300.50

41563 MASTOIDECTOMY (RADICAL OR MODIFIED RADICAL), MYRINGOPLASTY AND OSSICULAR CHAIN RECONSTRUCTION (Anaes.) (Assist.)

**Fee:** $1,365.85 **Benefit:** 75% = $1,024.40

41564 MASTOIDECTOMY (RADICAL OR MODIFIED RADICAL), OBLITERATION OF THE MASTOID CAVITY, BLIND SAC CLOSURE OF EXTERNAL AUDITORY CANAL AND OBLITERATION OF EUSTACHIAN TUBE (Anaes.) (Assist.)

**Fee:** $1,766.25 **Benefit:** 75% = $1,324.70

41596 RETROLABYRINTHINE VESTIBULAR NERVE SECTION or COCHLEAR NERVE SECTION, or

BOTH (Anaes.) (Assist.)

**Fee:** $1,607.05 **Benefit:** 75% = $1,205.30

41599 INTERNAL AUDITORY MEATUS, exploration by middle cranial fossa approach with cranial nerve decompression (Anaes.) (Assist.)

**Fee:** $1,607.05 **Benefit:** 75% = $1,205.30

41603 OSSEO-INTEGRATION PROCEDURE - implantation of titanium fixture for use with implantable bone conduction hearing system device, in patients:

- With a permanent or long-term hearing loss; and

- Unable to utilise conventional air or bone conduction hearing aid for medical or audiological reasons; and

- With bone conduction thresholds that accord to recognised criteria for the implantable bone conduction hearing device being inserted.

Not being a service associated with a service to which items 41554, 45794 or 45797 (Anaes.)

**Fee:** $465.50 **Benefit:** 75% = $349.15 85% = $397.40

41604 OSSEO-INTEGRATION PROCEDURE - fixation of transcutaneous abutment implantation of titanium fixture for use with implantable bone conduction hearing system device, in patients:

- With a permanent or long term hearing loss; and

- Unable to utilise conventional air or bone conduction hearing aid for medical or audiological reasons; and

- With bone conduction thresholds that accord to recognised criteria for the implantable bone conduction hearing device being inserted.

Not being a service associated with a service to which items 41554, 45794 or 45797 (Anaes.)

**Fee:** $172.30 **Benefit:** 75% = $129.25 85% = $146.50

41608 STAPEDECTOMY (Anaes.) (Assist.)

**Fee:** $1,006.95 **Benefit**: 75% = $755.25

41611 STAPES MOBILISATION (Anaes.) (Assist.) Fee: $647.85 **Benefit:** 75% = $485.90

41617 COCHLEAR IMPLANT, insertion of, including mastoidectomy (Anaes.) (Assist.)

**Fee:** $1,750.90 **Benefit:** 75% = $1,313.20

41626 ABSCESS OR INFLAMMATION OF MIDDLE EAR, operation for (excluding aftercare) (Anaes.)

**Fee:** $133.05 **Benefit:** 75% = $99.80 85% = $113.10

41629 MIDDLE EAR, EXPLORATION OF (Anaes.) (Assist.)

**Fee:** $481.55 **Benefit:** 75% = $361.20

41632 MIDDLE EAR, insertion of tube for DRAINAGE OF (including myringotomy) (Anaes.)

**Fee:** $220.65 **Benefit:** 75% = $165.50 85% = $187.60

41635 CLEARANCE OF MIDDLE EAR FOR GRANULOMA, CHOLESTEATOMA and POLYP, 1 or more, with or without myringoplasty (Anaes.) (Assist.)

**Fee:** $1,057.20 **Benefit:** 75% = $792.90 85% = $989.10

41638 CLEARANCE OF MIDDLE EAR FOR GRANULOMA, CHOLESTEATOMA and POLYP, 1 or more, with or without myringoplasty with ossicular chain reconstruction (Anaes.) (Assist.)

**Fee:** $1,319.55 **Benefit:** 75% = $989.70

41641 PERFORATION OF TYMPANUM, cauterisation or diathermy of (Anaes.)

**Fee:** $43.85 **Benefit:** 75% = $32.90 85% = $37.30

41644 EXCISION OF RIM OF EARDRUM PERFORATION, not being a service associated with myringoplasty (Anaes.)

**Fee:** $131.90 **Benefit:** 75% = $98.95 85% = $112.15

41647 EAR TOILET requiring use of operating microscope and microinspection of tympanic membrane with or without general anaesthesia (Anaes.)

**Fee:** $101.55 **Benefit:** 75% = $76.20 85% = $86.35

41650 TYMPANIC MEMBRANE, microinspection of 1 or both ears under general anaesthesia, not being a service associated with a service to which another item in this Group applies (Anaes.)

**Fee:** $101.55 **Benefit:** 75% = $76.20 85% = $86.35

41755 EUSTACHIAN TUBE, catheterisation of (Anaes.)

**Fee:** $42.95 **Benefit:** 75% = $32.25 85% = $36.55

45045 ARTERIOVENOUS MALFORMATION on eyelid, nose, lip, ear, neck, hand, thumb, finger or genitals, excision of (Anaes.)

**Fee:** $284.90 **Benefit:** 75% = $213.70 85% = $242.20

45206 SINGLE STAGE LOCAL FLAP where indicated to repair 1 defect, on eyelid, nose, lip, ear, neck, hand, thumb, finger or genitals, and excluding H-flap or double advancement flap (Anaes.)

**Fee:** $354.35 **Benefit:** 75% = $265.80 85% = $301.20

45448 FREE GRAFTING (split skin) to 1 defect, including elective dissection on eyelid, nose, lip, ear, neck, hand, thumb, finger or genitals, not being a service to which item 45442 or 45445 applies (Anaes.)

**Fee:** $347.35 **Benefit:** 75% = $260.55 85% = $295.25

45485 FREE GRAFTING (split skin) to burns, including excision of burnt tissue - upper eyelid, nose, lip,

ear or palm of the hand (Anaes.) (Assist.)

**Fee:** $487.50 **Benefit:** 75% = $365.65

45656 COMPOSITE GRAFT (Chondrocutaneous or chondromucosal) to nose, ear or eyelid (Anaes.) (Assist.)

**Fee:** $464.05 **Benefit:** 75% = $348.05 85% = $395.95

45659 LOP EAR, BAT EAR OR SIMILAR DEFORMITY, correction of (Anaes.)

**Fee:** $481.55 **Benefit:** 75% = $361.20 85% = $413.45

45660 EXTERNAL EAR, COMPLEX TOTAL RECONSTRUCTION OF, using multiple costal cartilage grafts to form a framework, including the harvesting and sculpturing of the cartilage and its insertion, for congenital absence, microtia or post-traumatic loss of entire or substantial portion of pinna (first stage) - performed by a specialist in the practice of his or her specialty (Anaes.) (Assist.)

**Fee:** $2,659.55 **Benefit:** 75% = $1,994.70

45661 EXTERNAL EAR, COMPLEX TOTAL RECONSTRUCTION OF, elevation of costal cartilage framework using cartilage previously stored in abdominal wall, including the use of local skin and

fascia flaps and full thickness skin graft to cover cartilage (second stage) - performed by a specialist in the practice of his or her specialty (Anaes.) (Assist.)

**Fee:** $1,182.05 **Benefit:** 75% = $886.55

45662 CONGENITAL ATRESIA, reconstruction of external auditory canal (Anaes.) (Assist.)

**Fee:** $647.85 **Benefit:** 75% = $485.90

45665 LIP, EYELID OR EAR, FULL THICKNESS WEDGE EXCISION OF, with repair by direct sutures

(Anaes.)

**Fee:** $301.20 **Benefit:** 75% = $225.90 85% = $256.05

45794 OSSEO-INTEGRATION PROCEDURE - extra-oral, implantation of titanium fixture, not for implantable bone conduction hearing system device (Anaes.)

**Fee:** $465.50 **Benefit:** 75% = $349.15 85% = $397.40

45797 OSSEO-INTEGRATION PROCEDURE, fixation of transcutaneous abutment, not for implantable bone conduction hearing system device (Anaes.)

**Fee:** $172.30 **Benefit:** 75% = $129.25 85% = $146.50

52010 FULL THICKNESS LACERATION OF EAR, EYELID, NOSE OR LIP, repair of, with accurate apposition of each layer of tissue (Anaes.) (Assist.)

**Fee:** $234.65 **Benefit:** 75% = $176.00 85% = $199.50

52480 COMPOSITE GRAFT (Chondro-cutaneous or chondro-mucosal) to nose, ear or eyelid (Anaes.) (Assist.)

**Fee:** $464.05 **Benefit:** 75% = $348.05 85% = $395.95

## Appendix H

## Acronyms and abbreviations

ABG Air-bone gap

ABI Auditory brainstem implant (ABI) AMI Auditory mid-brain implant

ABS Australian Bureau of Statistics

AC Air conduction

APHAB Abbreviated Profile of Hearing Aid Benefit

AR-DRG Australian Refined Diagnostic Related Group

ASERNIP-S Australian Safety and Efficacy Register of New Interventional

Procedures - Surgical

AV Aversiveness

BAHA Bone anchored hearing aid

BC Bone conduction

BN Background noise

CHERE Centre for Health Economics Research and Evaluation

CHL Conductive hearing loss

CI Cochlear implant

dB HL decibels hearing level

DDHS Direct Drive Hearing System

EAC External auditory canal

EC Ease of communication

EMSN Extended Medicare Safety Net

ENT Ear, nose and throat

FDA Food and Drug Administration

FMT Floating mass transducer GBI Glasgow Benefits Inventory HA Hearing aid

HEIP Hough Ear Institute Profile

HINT Hearing In Noise Test

HL Hearing loss

HTA Health technology assessment ICER incremental cost-effectiveness ratio MBS Medicare Benefits Schedule

MEI Middle ear implant MET Middle ear transducer MHL Mixed hearing loss

MPS maximum phoneme score

MRI Magnetic resonance imaging

MSAC Medical Services Advisory Committee NHMRC National Health and Medical Research Council PHAB Profile of Hearing Aid Benefit

PHAP Profile of Hearing Aid Performance

PICO Population, intervention, comparator, outcomes

PORP Partial ossicular replacement prosthesis

RV Reverberation

SHACQ Soundbridge Hearing Aid Comparison Questionnaire

SNHL Sensorineural hearing loss

SPIN Speech Perception in Noise (SPIN) test

SRT Speech Reception Threshold

TGA Therapeutic Goods Administration TORP Total ossicular replacement prosthesis VSB Vibrant Soundbridge

## References

Access Economics 2006, *The economic impact and cost of hearing loss in Australia* [Internet].

Access Economics, Victoria. Available from:

<http://www.audiology.asn.au/pdf/ListenHearFinal.pdf>[accessed 14 April 2009].

Altman D, Schulz K, et al, 2001. ‘The revised CONSORT statement for reporting randomized trials: explanation and elaboration’, *Annals of Internal Medicine*, 134,

663-694.

American Speech-Language-Hearing Association 2009, *Type, degree, and configuration of hearing loss* [Internet]. American Speech-Language-Hearing Association, USA. Available from: <http://www.asha.org/public/hearing/disorders/types.htm> [accessed 14 April 2009].

Arthur D, 2002. ‘The Vibrant® Soundbridge™’, *Trends in Amplification*; 6, 67-72. Australian Bureau of Statistics, 2007, *1301.0 - Year Book Australia, No. 89*,

Commonwealth of Australia, Canberra.

Australian Hearing 2008, *Types of hearing loss* [Internet]. Australian Hearing, Australia.

Available from: [www.hearing.com.au/types-of-hearing-loss](http://www.hearing.com.au/types-of-hearing-loss) [accessed 14 April

2009].

Australian Institute of Health and Welfare 2009, *Procedures Data Cubes* [Internet].

Australian Institute of Health and Welfare, Canberra. Available from: http://d01.aihw.gov.au/cognos/cgi- in/ppdscgi.exe?DC=Q&E=/ahs/proc\_0607 [accessed 16 July 2009].

Australian Institute of Health and Welfare, 2008, *Australia’s health 2008. Cat. no. AUS 99.*

Australian Institute of Health and Welfare, Canberra.

Australian Institute of Health and Welfare 2007, *Aboriginal and Torres Strait Islander Health Performance Framework, 2006 report: detailed analyses. Cat. no. IHW 20.* Australian Institute of Health and Welfare, Canberra.

Backous DD and Duke W, 2006. ‘Implantable middle ear hearing devices: current state of technology and market challenges’, *Current Opinion in Otolaryngology & Head and Neck Surgery,* 14, 314-318.

Badran K, Arya AK, et al, 2009. ‘Long-term complications of bone-anchored hearing aids: a 14-year experience’, *The Journal of Laryngology and Otology*, 123, 170-176.

Bailey BJ, Johnson JT, Newlands SD, 2006. *Head and neck surgery–otolaryngology,* 4th edn, Lippincott Williams & Wilkins, Philadelphia.

Bankaitis AU and Fredrickson JM, 2002. ‘Otologics Middle Ear Transducer™ (MET™) implantable hearing device: rationale, technology, and design strategies’, *Trends in Amplification*, 6, 53-60.

Barbara M, Manni V, Monini S, 2009. ‘Totally implantable middle ear device for rehabilitation of sensorineural hearing loss: preliminary experience with the Esteem, Envoy’, *Acta Oto-Laryngologica*, 129, 429-432.

Bennett M, Warren F, Haynes D, 2006. ‘Indications and Technique in Mastoidectomy’,

*Otolaryngologic Clinics of North America*, 39, 1095–1113.

Bentler RA, Niebuhr DP, Getta JP, Anderson CV, 1993. ‘Longitudinal study of hearing aid effectiveness. I: Objective measures’ *Journal of Speech & Hearing Research*, 36,

808-819.

Bentler RA, Niebuhr DP, Getta JP, Anderson CV, 1993a. ‘Longitudinal study of hearing aid effectiveness. II: Subjective measures’, *Journal of Speech & Hearing Research*, 36:

820-831.

Bibas A, Phillips S, et al, 2006. ‘Chronic suppurative otitis media following paediatric cochlear implantation’, *Cochlear Implants International*, 7, 167-178.

Biernath KR, Reefhuis J, et al, 2006. ‘Bacterial meningitis among children with cochlear implants beyond 24 months after implantation’, *Pediatrics*, 117, 284-289.

Brookhouser PE, Beauchaine KL, Osberger MJ, 1999. ‘Management of the child with sensorineural hearing loss. Medical, surgical, hearing aids, cochlear implants’, *Pediatric Clinics of North America*, 46, 121-41.

Brown KD, Connell SS, et al, 2009. ‘Incidence and indications for revision cochlear implant surgery in adults and children’, *The Laryngoscope*, 119, 152-157.

Canadian Coordinating Office for Health Technology Assessment (CCOHTA) 2003, Emerging Technology List. Semi-implantable, middle ear hearing aids [Internet]. Canadian Coordinating Office for Health Technology Assessment, Canada. Available from: http://www.cadth.ca/media/pdf/152\_No16\_implantablehearingaids\_etech\_e.pdf [accessed 25 February 2010].

Caye-Thomasen P, Jensen JH, et al, 2002. ‘Long-term results and experience with the first-generation semi-implantable electromagnetic hearing aid with ossicular replacement device for mixed hearing loss’, *Otology and Neurotology*, 23, 904-911.

Chang P, 2005. ‘Implantable hearing devices: beyond hearing aids’, *Australian Family*

*Physician*, 34, 157-161.

Chasin M, 2002. ‘Bone anchored and middle ear implant hearing aids’, *Trends in*

*Amplification*, 6, 33-38.

Chen DA, Backous DD, et al, 2004. ‘Phase 1 clinical trial results of the envoy system: a totally implantable middle ear device for sensorineural hearing loss’*, Otolaryngology Head and Neck Surgery,* 131, 904-916.

Coates HL, Morris PS, Leach AJ, Couzos S, 2002. ‘Otitis media in Aboriginal children:

tackling a major health problem’, *Medical Journal of Australia*, 177, 177-178.

Colletti V, Carner M, Colletti L, 2009. ‘TORP vs round window implant for hearing restoration of patients with extensive ossicular chain defect’, *Acta Oto- Laryngologica*, 129, 449-452.

Colletti V, Soli SD, et al, 2006. ‘Treatment of mixed hearing losses via implantation of a vibratory transducer on the round window’, *International Journal of Audiology*, 45,

600-608.

Comité d’Evaluation et de Diffusion des Innovations Technologiques (CEDIT) 2002,

‘Auditory rehabilitation in adults using middle ear implants’ [Internet]. Comite d’Evaluation et de Diffusion des Innovations Technologiques, France. Available from: [http://cedit.aphp.fr/servlet/siteCeditGB?Destination=reco&numArticle=01.11](http://cedit.aphp.fr/servlet/siteCeditGB?Destination=reco&amp;numArticle=01.11) [accessed 25 February 2010].

Cote M, Ferron P, et al, 2007. ‘Cochlear reimplantation: causes of failure, outcomes, and audiologic performance’, *The Laryngoscope*, 117, 1225-1235.

Counter P, 2008. ‘Implantable hearing aids’, *Proceedings of the Institution of Mechanical*

*Engineers. Part H, Journal of Engineering in Medicine*, 222, 837-852.

Cox RM, 1997. ‘Administration and application of the APHAB’, *The Hearing Journal*; 50,

32-48.

Cremers CWRJ, Verhaegen VJO, Snik AFM, 2008. ‘The floating mass transducer of the Vibrant Soundbridge interposed between the stapes and tympanic membrane after incus necrosis’, *Otology and Neurotology*, 30, 76-78.

Cuda D, Murri A, Tinelli N, 2009. ‘Piezoelectric round window osteoplasty for Vibrant

Soundbridge implant’, *Otology and Neurotology*, 30, 782-786.

Cullen RD, Fayad JN, et al, 2008. ‘Revision cochlear implant surgery in children’, *Otology and Neurotology*, 29, 214-220.

Cummings otolaryngology—head & neck surgery / [edited by] Charles W. Cummings et al. 4th ed. Rev. ed. of: Otolaryngology—head & neck surgery. Mosby, Philadelphia 2005

Davids T, Gordon KA, et al, 2007. ‘Bone-anchored hearing aids in infants and children younger than 5 years’, *Archives of Otolaryngology Head and Neck Surgery*, 133, 51-55.

Dodson KM, Maiberger PG, Sismanis A, 2007. ‘Intracranial complications of cochlear implantation’, *Otology and Neurotology*, 28, 459-462.

Dumon T, Gratacap B, et al, 2009. ‘Vibrant Soundbridge middle ear implant in mixed hearing loss. Indications, techniques, results’, *Revue de Laryngologie-Otologie- Rhinologie*, 130, 75-81.

Dumon T, 2007. ‘Vibrant Soundbridge middle ear implant in otosclerosis: technique –

indication’, *Advances in Oto-rhino-laryngology*, 65, 320-322.

Elliott LL, 1995. ‘Verbal auditory closure and the Speech Perception In Noise (SPIN)

test’, *Journal of Speech and Hearing Research*, 38, 1363-1376.

Fisch U, Cremers CWRJ, et al, 2001. ‘Clinical experience with the Vibrant Soundbridge implant device’, *Otology and Neurotology*, 22, 962-972.

Foyt D and Carfrae M, 2006. ‘Minimal access surgery for the Symphonix/Med-El

Vibrant Soundbridge middle ear hearing implant’, *Otology and Neurotology*, 27, 167-

171.

Fraysse B, Lavieille J-P, et al, 2001. ‘A multicenter study of the Vibrant Soundbridge middle ear implant: early clinical results and experience’ *Otology and Neurotology*, 22,

952-961.

Frenzel H, Hanke F, et al, 2009. ‘Application of the Vibrant Soundbridge to unilateral osseous atresia cases’, *The Laryngoscope*, 119, 76-74.

Fucci MN, Lippy WH, et al, 1998. ‘Prosthesis size in stapedectomy’, *Otolaryngology – Head and Neck Surgery*, 118, 1-5.

Garin P, Thill MP, et al, 2002. ‘Speech discrimination in background noise with the

Vibrant Soundbridge middle ear implant’, *Oto Rhino Laryngologia Nova*, 12, 119-

123.

Gelfand SA, 2009. *Essentials of audiology*, 3rd edn, Thieme Medical Publishers, Inc, New

York.

Gillett D, Fairley JW, et al, 2006. ‘Bone-anchored hearing aids: results of the first eight years of a programme in a district general hospital, assessed by the Glasgow benefit inventory’, *The Journal of Laryngology and Otology*, 120, 537-542.

Harvard Health Letter, 2007. ‘A better hearing aid?’, *Harvard Health Letter*, 32, 1-2. Holgers K-M, Tjellstrom A, Bjursten LM, Erlandsson B-E, 1988. ‘Soft tissue reactions

around percutaneous implants: a clinical study of soft tissue conditions around skin-penetrating titanium implants for bone-anchored hearing aids’, *American Journal of Otology*, 9, 56-59.

Holt JJ, 2003. ‘Cholesteatoma and otosclerosis: two slowly progressive causes of hearing loss treatable through corrective surgery’, *Clinical Medicine & Research*; 1, 151-4.

Hopfenspirger MT, Levine SC, Rimell FL, 2007. ‘Infectious complications in pediatric cochlear implants’, *The Laryngoscope*, 117, 1825-1829.

Hough JVD, Dyer RK, et al, 2001. ‘Early clinical results: SOUNDTEC implantable hearing device phase II study’, *The Laryngoscope,* 111, 1-8.

Huttenbrink K-B, 2001. ‘Middle ear mechanics and their interference with respect to implantable electronic otologic devices’, *Otolaryngologic Clinics of North America*, 34,

315-35.

Javia LR and Ruckenstein MJ, 2006. ‘Ossiculoplasty’, *Otolaryngologic Clinics of North*

*America*, 39, 1177-89.

Jenkins HA, Atkins JS, et al, 2007. ‘US Phase I preliminary results of use of the Otologics

MET fully-implantable ossicular stimulator’, *Otolaryngology – Head and Neck*

*Surgery*, 137, 206-212.

Jenkins HA, Niparko JK, et al, 2004. ‘Otologics Middle Ear Transducer ossicular stimulator: performance results with varying degrees of sensorineural hearing loss’, *Acta Otolaryngologica*, 124, 391-394.

Kodera K, Suzuki J, et al, 1994. ‘Sound evaluation of partially implantable piezoelectric middle ear implant: comparative study of frequency response’, *ENT Journal*, 73,

108-111.

Koopman JP, Reuchlin AG, Kummer EE, Boumans LJJM, Rijntjes E, Hoeve LJ, Mulder PGH, Blom HM, 2004. ‘Laser myringotomy versus ventilation tubes in children with otitis media with effusion: a randomized trial’, *The Laryngoscope*, 114, 844-849.

Kroll K, Grant IL, Javel E, 2002. ‘The Envoy totally implantable hearing system, St.

Croix Medical’, *Trends in Amplification,* 6, 73-80.

Kulkarni K and Hartley DEH, 2008. ‘Recent advances in hearing restoration’, *Journal of the Royal Society of Medicine*, 101, 116-124.

Lalwani AK (ed) *Current Diagnosis and Treatment in Otolaryngology Head Neck Surgery* 2nd ed.

McGraw-Hill Companies, Inc., New York, 2008.

Lassaletta L, Castro A, et al, 2006. ‘Quality of life in postlingually deaf patients following cochlear implantation’, *European Archives of Otorhinolaryngology*, 263, 267-270.

Lee KJ, 2002, *Essential Otolaryngology: Head & Neck Surgery,* 8th ed. McGraw-Hill

Professional, New York.

Lefebvre PP, Martin C, et al, 2009. ‘A pilot study of the safety and performance of the Otologics fully implantable hearing device: transducing sounds via the round window membrane to the inner ear’, *Audiology and Neurotology*, 14, 172-180.

Lescanne E, Bakhos D, et al, 2008. ‘Otosclerosis in children and adolescents: a clinical and CT-scan survey with review of the literature’, *International Journal of Pediatric Otorhinolaryngology,* 72, 147-52.

Lin Y-S, Lee F-P, Peng S-C, 2006. ‘Complications in children with long-term cochlear implants’, *ORL*, 68, 237-242.

Lloyd S, Almeyda J, et al, 2007. ‘Updates surgical experience with bone-anchored hearing aids in children’, *The Journal of Laryngology and Otology*, 121, 826-831.

Lloyd S, Meerton L, et al, 2007a. ‘Taste change following cochlear implantation’, *Cochlear*

*Implants International*, 8, 203-210.

Luetje CM, Brackman D, et al, 2002. ‘Phase III clinical trial results with the Vibrant Soundbridge implantable middle ear hearing device: a prospective controlled multicenter study’, *Otolaryngology – Head and Neck Surgery*, 126, 97-107.

Manrique M, Valdivieso A, et al, 2008. ‘Review of audiometric criteria in treatment of neurosensorial deafness with hearing aids and implantable hearing devices’, *Acta Otorrinolaringologica Espanola*, 59, 30-8.

Matthews P, 2002. ‘The SOUNDTEC Direct System’, *Trends in Amplification*, 6, 61-65. Medicare Australia 2009, *Medicare Item Reports* [Internet]. Medicare Australia,

Tuggeranong. Available at:

[https://www.medicareaustralia.gov.au/statistics/](http://www.medicareaustralia.gov.au/statistics/mbs_item.shtml)m[bs\_item.sh](http://www.medicareaustralia.gov.au/statistics/mbs_item.shtml)tml [accessed 16

July 2009].

Merchant SN and Rosowski JJ, 2008. ‘Conductive hearing loss caused by third-window lesions of the inner ear’, *Otology and Neurotology*, 29, 282-9.

Merlin T, Weston A, Tooher R, 2009. ‘Extending an evidence hierarchy to include topics other than treatment: revising the Australian 'levels of evidence'’, *BMC Medical Research Methodology*, 9, 34.

Migirov L, Taitelbaum-Swead R, et al, 2007. ‘Revision surgeries in cochlear implant patients: a review of 45 patients’, *European Archives of Otorhinolaryngology*, 264, 3-7.

Migirov L, Muchnik C, et al, 2006. ‘Surgical and medical complications in paediatric cochlear implantation: a review of 300 cases’, *Cochlear Implants International*, 7, 194-

201.

Moeller MP, 2007. ‘Current state of knowledge: psychosocial development in children with hearing impairment’, *Ear and Hearing,* 28, 729-39.

Mosnier I, Sterkers O, et al, 2008. ‘Benefit of the Vibrant Soundbridge device in patients implanted for 5 to 8 years’, *Ear and Hearing*, 29, 281-284.

Murugasu E, 2005. ‘Recent advances in the treatment of sensorineural deafness’, *Annals of the Academy of Medicine, Singapore*, 34, 313-321.

National Acoustic Laboratories 2000-2005, *Instructions for COSI™ Administration* [Internet]. National Acoustic Laboratories, New South Wales. Available at: <http://www.nal.gov.au/pdf/COSI-administration-instructions.pdf>[accessed 2

February 2010].

National Institute for Health and Clinical Excellence, 2009, *Cochlear implants for children and adults with severe to profound deafness. NICE technology appraisal guidance 166*, National Institute for Health and Clinical Excellence, London.

Newton VE (ed) *Paediatric audiological medicine* 2nd ed. John Wiley & Sons, Ltd., West

Sussex, 2009.

NHMRC (1999). A guide to the development, implementation and evaluation of clinical practice guidelines, National Health and Medical Research Council, Canberra.

NHMRC (2000). How to use the evidence: assessment and application of scientific evidence, National Health and Medical Research Council, Canberra.

O’Leary S and Chang A, 2008. ‘Hearing impairment – technological advances and insights’, *Australian Family Physician*, 37, 322-327.

Ovesen T and Johansen LV, 2009. ‘Post-operative problems and complications in 313 consecutive cochlear implantations’, *The Journal of Laryngology and Otology*, 123,

492-496.

Postelmans JTF, Cleffken B, Stokroos RJ, 2007. ‘Post-operative complications of cochlear implantation in adults and children: five years’ experience in Maastricht’, *The Journal of Laryngology and Otology*, 121, 318-323.

Ramsden R, Rotteveel L, et al, 2007. ‘Cochlear implantation in otosclerotic deafness’,

*Advances in Otorhinolaryngology*, 65, 328-334.

Reefhuis J, Honein MA, et al, 2003. ‘Risk of bacterial meningitis in children with cochlear implants’, *New England Journal of Medicine*, 349, 435-445.

Robinson K, Gatehouse S, Browning GG, 1996. ‘Measuring patient benefit from otorhinolaryngological surgery and therapy’, *Annals of Otology, Rhinology and Laryngology*, 105, 415-422.

Rodriguez K, Shah RK, Kenna M, 2007. ‘Anomalies of the middle and inner ear’,

*Otolaryngologic Clinics of North America*, 40, 81-96.

Roland PS, Shoup AG, et al, 2001. ‘Verification of improved patient outcomes with a partially implantable hearing aid, the SOUNDTEC Direct Hearing System’, *The Laryngoscope*, 111, 1682-1686.

Rovers MM, 2008. ‘The burden of otitis media’, *Vaccine,* 26S, G2-G4.

Samy RN and Pensak ML, 2006. ‘Revision ossiculoplasty’, *Otolaryngologic Clinics of North*

*America*, 39, 699-712.

Schmuziger N, Schimmann F, et al, 2006. ‘Long-term assessment after implantation of the Vibrant Soundbridge device’, *Otology and Neurotology*, 27, 183-188.

Shinners MJ, Hilton CW, Levine SC, 2008. ‘Implantable hearing devices’, *Current Opinion in Otolaryngology & Head and Neck Surgery,* 16, 416-419.

Shoman N, Ngo R, et al, 2008. ‘Prevalence of new-onset vestibular symptoms following cochlear implantation’, *Journal of Otolaryngology – Head and Neck Surgery*, 37, 388-

394.

Siegert R, Mattheis S, Kasic J, 2007. ‘Fully implantable hearing aids in patients with congenital auricular atresia’, *The Laryngoscope*, 117, 336-340.

Smoski WJ, 2008, Speech audiometry [Internet]. Medscape, USA. Available at:

<http://emedicine.medscape.com/article/835840-overview>[accessed 2 February

2010].

Snik AFM, van Duijnhoven, et al, 2007. ‘Evaluation of the subjective effect of middle ear implantation in hearing-impaired patients with severe external otitis’, *Journal of the American Academy of Audiology,* 18, 496-503.

Snik AFM, van Duijnhoven NTL, et al, 2006. ‘Estimated cost-effectiveness of active middle-ear implantation in hearing-impaired patients with severe external otitis’, *Archives of Otolaryngology Head and Neck Surgery*, 132, 1210-1215.

Snik A, Noten J, Cremers C, 2004. ‘Gain and maximum output of two electromagnetic middle ear implants: are real ear measurements helpful?’ *Journal of the American Academy of Audiology*, 15, 249-257.

Snik A and Cremers C, 2004a. ‘Audiometric evaluation of an attempt to optimize the fixation of the transducer of a middle-ear implant to the ossicular chain with bone cement’, *Clinical Otolaryngology and Allied Sciences,* 29, 5-9.

Snik AFM and Cremers CWRJ, 2001. ‘Vibrant semi-implantable hearing device with digital sound processing’, *Archives of Otolaryngology Head and Neck Surgery*, 127,

1433-1437.

Snik AFM and Cremers CWRJ, 2000. ‘The effect of the “floating mass transducer” in the middle ear on hearing sensitivity’, *The American Journal of Otology*, 21, 42-48.

Snik AFM and Cremers CWRJ, 1999. ‘First audiometric results with the Vibrant Soundbridge, a semi-implantable hearing device for sensorineural hearing loss’, *Audiology*, 38, 335-338.

Stalfors J and Tjellstrom A, 2008. ‘Skin reactions after BAHA surgery: a comparison between the U-graft technique and the BAHA dermatome’, *Otology and Neurotology*, 29, 1109-1114.

Sterkers O, Boucarra D, et al, 2003. ‘A middle ear implant, the Symphonix Vibrant Soundbridge: retrospective study of the first 125 patients implanted in France’, *Otology and Neurotology*, 24, 427-436.

Stieve M, Winter M, et al, 2009. ‘The influence of the coupling of actuation drivers of implantable hearing systems on the mechanics of the middle ear’, *Cochlear Implants International*, 10, 160-165.

Stratigouleas ED, Perry BP, et al, 2006. ‘Complication rate of minimally invasive cochlear implantation’, *Otolaryngology – Head and Neck Surgery*, 135, 383-386.

Streitberger C, Perotti M, et al, 2009. ‘Vibrant Soundbridge for hearing restoration after chronic ear surgery’, *Revue de Laryngologie-Otologie-Rhinologie*, 130, 83-88.

Suzuki J-I, Kodera K, et al, 1995. ‘Partially implantable piezoelectric middle ear hearing device: long term results’, *Otolaryngologic Clinics of North America*, 28, 99-107.

Suzuki J-I, Kodera K, et al, 1994. ‘Long-term clinical results of the partially implantable piezoelectric middle ear implant’, *ENT Journal*, 73, 104-107.

Suzuki JI, Kodera K, et al, 1989. ‘Further clinical experiences with middle-ear

implantable hearing aids: indications and sound quality evaluation’, *ORL*, 51, 229-

234.

Symphonix Devices, Incorporated, 2000. ‘Summary of safety and effectiveness’ available at: <http://www.accessdata.fda.gov/cdrh_docs/pdf/P990052b.pdf>

Taibah K, 2009. ‘The transmeatal approach: a new technique in cochlear and middle ear implants’, *Cochlear Implants International*, 10, 218-228.

Thill M-P, Gerard J-M, et al, 2002. ‘Belgian experience with the Vibrant Soundbridge prosthesis’, *Acta Oto-rhino-laryngologica Belgica*, 56, 375-378.

Tjellstrom A, Granstrom G, Odersjo M, 2007. ‘Survival rate of self-tapping implants of bone-anchored hearing aids’, *The Journal of Laryngology and Otology*, 121, 101-104.

Tjellstrom A, Hakansson B, Granstrom G, 2001. ‘Bone-anchored hearing aids. Current status in adults and children’, *Otolaryngologic Clinics of North America,* 34, 337-64.

Todt I, Seidl RO, Ernst A, 2005. ‘Hearing benefit of patients after Vibrant Soundbridge implantation’, *ORL*, 67, 203-206.

Todt I, Seidl RO, et al, 2004. ‘MRI scanning and incus fixation in Vibrant Soundbridge implantation’, *Otology and Neurotology*, 25, 969-972.

Todt I, Seidl RO, et al, 2002. ‘Comparison of different Vibrant Soundbridge audioprocessors with conventional hearing aids’, *Otology and Neurotology*, 23, 669-

673.

Tono T, Inaba J, et al, 2000. ‘Clinical experience with partially implantable middle ear implant’, *Advances in Otorhinolaryngology*, 57, 186-188.

Tos M, Salomon G, Bonding P, 1994. ‘Implantation of electromagnetic ossicular replacement device’, *ENT Journal*, 73, 92-103.

Tringali S, Pergola N, et al, 2009. ‘Fully implantable hearing device with transducer on the round window as a treatment of mixed hearing loss’, *Auris Nasus Larynx*, 36,

353-358.

Tringali S, Pergola N, et al, 2008. ‘Fully implantable hearing device as a new treatment of conductive hearing loss in Franceschetti syndrome’, *International Journal of Pediatric Otorhinolaryngology*, 72, 513-517.

Truy E, Philibert B, et al, 2008. ‘Vibrant Soundbridge versus conventional hearing aid in sensorineural high-frequency hearing loss: a prospective study’, *Otology and Neurotology*, 29, 684-687.

Uziel A, Mondain M, et al, 2003. ‘Rehabilitation for high-frequency sensorineural hearing impairment in adults with the Symphonix Vibrant Soundbridge: a comparative study’, *Otology and Neurotology*, 24, 775-783.

Verhaegen VJO, Mylanus EAM, et al, 2008. ‘Audiological application criteria for implantable hearing aid devices: a clinical experience at the Nijmegen ORL clinic.’ *The Laryngoscope*, 118, 1645-1649.

Venail F, Lavieille JP, et al, 2007. ‘New perspectives for middle ear implants: first results in otosclerosis with mixed hearing loss’, *The Laryngoscope*, 117, 552-555.

Viccaro M, Mancini P, et al, 2007. ‘Positional vertigo and cochlear implantation’, *Otology and Neurotology*, 28, 764-767.

Vincent C, Fraysse B, et al, 2004. ‘A longitudinal study on postoperative hearing thresholds with the Vibrant Soundbridge device’, *European Archives of Otorhinolaryngology*, 261, 492-496.

Wade PS, 2002. ‘Medical aspects of bone anchored hearing aids and middle ear implants’,

*Trends in Amplification*, 6, 39-44.

Weissman JL, 1996. ‘Hearing loss’, *Radiology*, 199, 593-611.

Wilson BS and Dorman MF, 2008. ‘Cochlear implants: current designs and future possibilities’, *Journal of Rehabilitation Research & Development*, 45, 695-730.

Wilson D, Walsh PG, Sanchez L, Read P, 1998. *Hearing Impairment in an Australian Population,* South Australian Department of Human Services Centre for Population Studies in Epidemiology, Adelaide.

Winter M and Lenarz T, 2005. ‘The RetroX semi-implantable bearing system’, *Cochlear*

*Implants International*, 6, 62-65.

Wood MW and Hough JVD, 2002. ‘Implantable hearing devices: contemporary options’,

*Current Opinion in Otolaryngology & Head and Neck Surgery*, 10, 350-354.

Wootten CT, Backous DD, Haynes DS, 2006. ‘Management of cerebrospinal fluid leakage from cochleostomy during cochlear implant surgery’, *The Laryngoscope*,

116, 2055-2059.

Yanagihara N, Sato H, et al, 2001. ‘Long-term results using a piezoelectric semi- implantable middle ear hearing device’, *Otolaryngologic Clinics of North America*, 34,

389-400.

Yanagihara N, Hinohira Y, Gyo K, 1997. ‘Surgical rehabilitation of deafness with partially implantable hearing aid using piezoelectric ceramic bimorpli ossicular vibrator’, *Auris Nasus Larynx*, 24, 91-98.

Yueh B, Shapiro N, MacLean CH, Shekelle PG, 2003. ‘Screening and management of adult hearing loss in primary care’, *JAMA*, 289, 1976-1985.

Yuen H-W, Bodmer D, et al, 2009. ‘Management of single-sided deafness with the bone- anchored hearing aid’, *Otolaryngology – Head and Neck Surgery*, 141, 16-23.

Yung MW, 1996. ‘Local anaesthesia in middle ear surgery: survey of patients and surgeons’, *Clinical Otolaryngology and Allied Sciences*, 21, 393-397.

Zenner PH, Limberger A, et al, 2004. ‘Phase III results with a totally implantable piezoelectric middle ear implant: speech audiometry, spatial hearing and psychosocial adjustment’, *Acta Oto-Laryngologica*, 124, 155-164.

Zenner HP, Baumann JW, et al, 2003. ‘Patient selection for incus body coupling of a totally implantable middle ear implant’, *Acta Otolaryngologica*, 123, 683-696.

Zenner HP, 2000. ‘TICA totally implantable system for treatment of high-frequency sensorineural hearing loss’, *ENT Ear Nose and Throat*, 79, 770-777.