QS8 Electroacoustic checks must be performed regularly and whenever a part of the system is changed.

Checks with auditory implant systems – Updated v.2.0 March 2022

Remote Microphone (RM) systems include full-featured radio aids and proprietary remote microphones, for example the Cochlear MiniMic range, the MED-EL AudioLink or the Oticon EduMic etc.

Periodic comprehensive monitoring of the RM system including electroacoustic analysis and other in-depth troubleshooting measures should occur. These comprehensive procedures should also be performed whenever an unresolved problem is identified during a standard check. In any event, they should be performed routinely at least once a year children 5 years of age or older. They should be performed more frequently for children under 5 years of age – perhaps as often as every 3 to 6 months (ASHA 2002; NDCS 2017: QS4, QS7, QS8).

Electroacoustic test signals in quiet clinical settings[1]

Some cochlear implant processors have first-stage compression which can be observed. Although signals of equal intensity are used, it may be useful to present a softer signal to those processors where possible (Whyte 2019).

Table 1.

Cochlear Implant (CI) processor	SPL level to processor	SPL level to Remote Microphone (RM)
All Advanced Bionics processors	65 dB	65 dB
MED-EL SONNET and RONDO series	55 dB	55 dB
Cochlear Nucleus 7 and 6	55 dB	55 dB

[1] Values for other processors can be provided on request.
Oticon Medical CI cannot be tested in this manner.

Electroacoustic test signals in non-clinical settings

Table 2.

Auditory Implant (AI) processor	SPL level to processor	SPL level to Remote Microphone (RM)
AI sound processors tested in non-clinical settings	65 dB	65 dB

An acoustic transparency method with signals of equal intensity can be used with all hearing devices, even with non-linear signal processing (Husstedt et al., 2022).

Signals for BCHI sound processors

BCHI signal processing is more conventional.

Table 3.

Device	SPL level to processor	SPL level to RM
Bone conduction devices	65 dB	65 dB

Telecoil responses are known to be reduced in the lower frequencies to avoid interference in this area (Putterman & Valente, 2012). So, with induction-loop radio aid systems the curve will be reduced in the lower frequencies and the response curves are more likely to match above 1 kHz.

It is thought that signals of equal intensity will be similarly compressed by implant sound processors and a signal below the compression level may not be necessary (Husstedt op. cit.). Further research is being conducted to establish the suitability of signal levels through qualitative methods and behavioural testing. Members of the UK Children's Assistive Listening Technology Working Group have begun to undertake such research by considering the UK, EU and US protocols and their relation to speech-in-noise performance. In addition the UK study has begun to look at the output response of the implant at the electrode level.

In the interim, in quiet clinical settings, the Working Group advises, where environmental conditions allow, to use the values suggested for Auditory Implant[2] sound processors (Table 1). In non-clinical settings test signal inputs of 65 dB SPL may be used (Table 2).

[2] Cochlear implants, Bone Conduction Implants and Middle-ear Implants.

For guidance on Marvel hearing devices and Roger direct see:

https://www.batod.org.uk/wp-content/uploads/2022/02/Practical-Considerations-of-the-Phonak-Marvel-Aids-and-Radio-Aids-Final.pdf

How to record the responses.

A calibrated hearing instrument test (HIT) box is required and suitable leads and adapters for the hearing devices (Appendix 1).

For processors with front-end compression (Table 1) in quiet clinical settings present:

- To the processor: a frequency response curve with a digital speech signal or speech-weighted signal at 55dB input.
- To the remote microphone (RM): a frequency response curve with a digital speech signal or speech-weighted signal at 55dB input.

Otherwise, present:

- To the processor: a frequency response curve with a digital speech signal or speech-weighted signal at 65dB input.
- To the remote microphone (RM): a frequency response curve with a digital speech signal or speech-weighted signal at 65dB input.

Adjust the volume/gain of the remote microphone, or 'FM advantage' or 'EasyGain' level of the radio aid receiver so that the combined system response curve matches the sound processor response curve and achieves 'transparency' or 'balance'. *If the difference is 2 dB larger than the measurement tolerance (Table 4), then two output signals are different and transparency is not achieved – continue adjusting.* For example, in the Aurical HIT, if the two response are within 3 dB, then transparency is achieved.

Adjusting the receiver should preferably be done by starting at a low gain and then increasing.

Table 4.

Tolerance or signal accuracy up to 5000 Hz		Transparency difference overall
Affinity	< ± 1.5 dB	± 3.5 dB
Audioscan	± 1.0 dB	± 3.0 dB
Aurical	± 1.0 dB	± 3.0 dB
FP35	± 2.5 dB	± 4.5 dB

EUHA guidelines (2017) suggest ±5 dB for transparency and may be a cover-all value for all hearing instrument test boxes.

How to evaluate transparency

There are two standard methods to evaluate transparency (1 and 2), an extended method (3), and two methods that require examination of the source files, XML conversion and more complex calculations (4 and 5).

1. **By eye** – The processor responses without and with the and the remote microphone should overlap. If using the Aurical HIT, the gain difference table should show suitable values for each pair of curves (CI) and (CI + RM).

2. **Standard protocol** – compare the mid-frequency average for processor responses without and with the and the remote microphone.

Frequency (Hz)	750	1000	2000	Average	Difference
CI dB (SPL)	a	b	c	$A_1 = (a+b+c)/3$	
CI & RM dB (SPL)	x	y	z	$A_2 = (x+y+z)/3$	$A_2 - A_1$

3. **Adapted offset protocol** – calculate a wider frequency average for processor responses without and with the and the remote microphone, 750 Hz to 4000 Hz.

Frequency (Hz)	750	1000	1500	2000	3000	4000	Average	Difference
CI dB (SPL)	a	b	c	d	e	f	A_1	
CI & RM dB (SPL)	u	v	w	x	y	z	A_2	$A_2 - A_1$

$A_1 = (a+b+c+d+e+f)/6$
$A_2 = (u+v+w+x+y+z)/6$

4. **New RMS protocol** – calculate the broad average for processor responses without and with the and the remote microphone and compare (BSI, 2021).

Compute the root mean square of the difference in one-third octave levels from 800 Hz to 5 kHz of the output signal of the processor with the output signal of processor and RM combined. If the difference is 2 dB larger than the measurement tolerance*, then two output signals are different.

Frequency (Hz)	800	1000	1250	1600	2000	2500	3150	4000	5000	RMS	Difference
CI dB (SPL)	a	b	c	d	e	f	g	h	i	R_1	
CI & RM dB (SPL)	r	s	t	u	v	w	x	y	z	R_2	$R_2 - R_1$

$R_1 = \sqrt{((a^2+b^2+c^2+d^2+e^2+f^2+g^2+h^2+i^2)/9)}$
$R_2 = \sqrt{((r^2+s^2+t^2+u^2+v^2+w^2+x^2+y^2+z^2)/9)}$

5. **New EUHA protocol** (EUHA, 2017; Husstedt et al., 2021)

    1. Measure the output characteristic of the hearing device using an ISTS of 65 dB in a frequency range between 800 Hz and 3.5 kHz.
    2. Connect the hearing device to the RM system and place the remote microphone at a quiet position outside the test box. Measure the output characteristic of the hearing device using an ISTS of 65 dB in a frequency range between 800 Hz and 3.5 kHz. In this frequency range, the output characteristic should equal (±5 dB) the characteristic of step 1.
    3. Place the remote microphone inside the test box and place the hearing device at a quiet position outside the test box. Measure the output characteristic of the hearing device connected to the RM system using an ISTS of 65 dB in a frequency range between 800 Hz and 3.5 kHz. The measurement result is to equal the characteristic measured in step 1 (±5 dB). If necessary, adjust the setting of the RM system accordingly.
    4. *Verification of the measurement conditions* (empty test box): Place both the hearing aid and the remote microphone outside the test box. Make sure that there is a connection between the hearing aid and the WRM system, as in step 2 and step 3. Measure the output characteristic of the hearing aid. In a frequency range between 800 Hz and 3.5 kHz, this characteristic needs to be *at least 10 dB below the characteristic of step 1*.

Regardless of method, at the end of the testing, Save, Print, and Share the information (QS11).

Of utmost importance is the perception of the user and speech testing will help evaluate the fitting. Having verified the fitting, the most important things to consider are behavioural responses, user perception and to ***validate*** *with speech in noise testing with and without the remote microphone system to assess benefit.*

Background information on the development of the protocol

It is important that any protocol for completing electroacoustic measures with CI and BCHI and remote microphone systems is validated. Further research into this field is ongoing but this document sets out the UK position and some guidance that builds on from previous Good Practice Guidance (GPG).

In the UK, Teachers of the Deaf (TOD) work in line with their specialist Mandatory Qualification (NCTL 2016). Outcomes of this training include knowledge of:

- The theory and application of current practice and protocols.
- The range of available classroom related audiological equipment and amplification systems; and how to use them appropriately and effectively in different acoustic environments to optimise progress and achievements.
- Routine day-to-day maintenance of classroom based audiological and amplification equipment and other specialist technology and check that they are working to specification.
- How to evaluate the effectiveness of classroom based audiological and amplification equipment; strategies to maximise listening skills and how to help children to make effective use of their amplification to develop these skills.
- How to maximise the use of specialist equipment and technology to facilitate learning and progress.
- Collaborative working to ensure that staff, families and other professionals work together effectively to achieve best practice and maximise achievement for deaf learners. NCTL (2016 Annex A).

It is essential, therefore, that both initial training and continuing professional development courses are evidence-based and that training and guidance reflects on recent research, important developments and relevant innovations – including current specialist equipment.

Checks with auditory implant systems

As part of the usual setting up procedures for remote microphone systems, a check of the whole system is recommended (see also GPG QS4 and QS7.)

To support timely and appropriate provision regular electroacoustic (test box) checks and speech testing should be carried out

- to review frequency responses (QS 8);
- to ensure that the remote microphone signal provides the desired advantage (QS3); and
- to determine benefit (QS10).

Only the user can truly monitor their perception of the output of the combination of their sound processor and assistive listening device. For this reason, behavioural testing is recommended when fitting remote microphone systems to individuals with

auditory implants – Cochlear Implants (CI[3]) or Bone Conduction Hearing Devices and Middle Ear Implants (Bone Conducting Hearing Implants, BCHI[4]).

Auditory implant recipients are likely to be seen annually in clinic but, through good liaison with professionals, (QS5) local Teachers of the Deaf or Educational Audiologists see the remote microphone user more frequently.

When to fit remote microphones with implants?

QS1 considers potential candidacy for remote microphone provision as part of the amplification at first hearing aid fitting. For auditory implants, particularly cochlear implants, there will be an extensive process of habilitation. A cochlear implant is a device which stimulates the nerve of hearing electrically. It takes a long time for people to adjust to the sounds that a cochlear implant provides and frequent tuning appointments are necessary. The sensation that the electrodes of the implant provide bears no comparison to the quality of sound that the thousands of hair cells in a normally hearing person's cochlea gives. The greatly compressed signals of the implant are received by the brain and the user learns to interpret the stimulation as meaningful sound.

There is a natural period of time before remote microphone systems can be introduced to cochlear implant users and their implant centre professionals will advise on this. Individual circumstances need to be taken into account. Generally the implant will need to settle down in the ear; the user will need to move through incremental implant maps, get used to the sound and progress to an optimised map. Initially children may not be able to give reliable behavioural measurements. There can be some estimation in the implant mapping and it can take time and further measures to be confident of an optimised map.

If a unilateral implant user goes on to have a sequential implant, there will need to be a similar period of time for the user to have meaningful access to speech with the new implant. The user's implant centre professionals will advise on habilitation and remote microphone use.

Background

The original work with cochlear implants commissioned by the UK Children's FM Working Group (now UK Children's Radio Aid Working Group) involved professionals and manufacturers from the field. Work by the University of Southampton, the Ewing

[3] https://www.nice.org.uk/guidance/ta166/ , https://www.england.nhs.uk/commissioning/wp-content/uploads/sites/12/2014/04/d09-ear-surg-coch-0414.pdf and http://www.bcig.org.uk/wp-content/uploads/2016/05/BCIG-Quality-Standard-2016.pdf (Accessed 29 March 2022)

[4] https://www.england.nhs.uk/commissioning/wp-content/uploads/sites/12/2013/05/16041_FINAL.pdf and https://www.england.nhs.uk/wp-content/uploads/2013/04/d09-p-a.pdf (Accessed 29 March 2022)

Foundation and Connevans Ltd led to the manufacture of dedicated implant test leads. Initial measurements were made using monitor earphones and acoustic putty and this approach is still used in the United States of America (Schafer et al. 2013; Nair et al. 2017).

The Working Group 2008 Good Practice Guidance protocol was based on work from the group's inception in 2004, its initial proposals and later studies (e.g. Newman and Hostler 2008). The group's work drew from international innovation with hearing aids (e.g. Lewis & Eiten 2000; ASHA 2002; and AAA 2011) and national initiatives like the 2000–2005 Modernising Children's Hearing Aid Services (MCHAS) programme[5] in England.

Initial UK studies with cochlear implants used test signals of equal intensity in line with MCHAS FM Advantage procedures[6] with non-linear amplification. Following feedback from users with technology of the period the intensity of the radio aid signal was reduced by delivering a signal of 5 dB less to the CI sound processor and matching the radio aid to this (Harris 2006; Wood 2008). However, advances in sound processor technology have led to appropriate signals of equal intensity being recommended (Whyte 2019, 2020).

Working Group protocol

The South of England Cochlear Implant Centre (now the University of Southampton Auditory Implant Service, USAIS) worked collaboratively with others specialist contributors from the Working Group. For sound processors with an audio output path a test protocol was established by the working group.

The monitor earphone adapter or accessories socket provides the possibility to objectively test and confirm the processor's 'front-end' mixing and frequency response when used in conjunction with a hearing instrument test box and specialist equipment. For example, microphone test devices or audio adapters and direct connection test leads[7].

Ensure that the appropriate settings of the sound processor (e.g., programs, telecoil function and audio mixing ratio) are enabled by the Auditory Implant Service and that the remote microphone and receiver (if applicable) are available from the Education service (and its connection adapters or direct audio leads if required).

Separate listening checks of the sound processor(s) and remote microphone and the *whole system combined* should be carried out. Electroacoustic testing can then be

[5] http://research.bmh.manchester.ac.uk/mchas/aboutus/guidelines
[6] https://www.connevans.info/image/connevans/B0FMADV.pdf
[7] https://www.connevans.co.uk/productSearch.do?query=dctest

carried out [8] in quiet conditions with an appropriately calibrated test box with measures recorded in SPL.

The original transparency procedures utilised the initial 'front-end' processing of the signal – this was effectively linear in early sound processors. That signal was subsequently adapted by the automatic gain control (AGC) circuits of the sound processor and delivered to the user as an electrical sensation of sound.

Cochlear introduced some compression to the front-end processing to the Nucleus 6 series of processors (and in subsequent generations). This auto-sensitivity (ASC) engages at 57 dB SPL and results in compression of the input signal. Front-end compression is also observed in the Nucleus7. With the release of the MED-EL Microphone Test Device Kit for SONNET front-end compression was also observed in electroacoustic checks. Following advice to the Working Group, the test box procedure was adapted a lower intensity, to present signals below the compression level in clinical settings. There is no front-end compression in Advanced Bionics processors. An acoustic transparency method with signals of equal intensity can be used with all hearing devices, even with non-linear signal processing (Husstedt et al., 2022). Appropriate signals are listed in Tables 1 – 3.

Further work

Independently of the UK Working Group, a protocol for cochlear implants was proposed by researchers in the United States of America and for hearing aids in the European Union (EUHA 2017). Schafer et al. (2013) proposed using signals of equal intensity (65 dB SPL to the processor and 65 dB SPL to the remote microphone) with transparency or balance achieved if the responses were within 3 dB.

Wolfe & Schafer (2015) suggested that transparency with cochlear implants and remote microphones should be achieved with equal inputs. A study to verify the US protocol suggested that electroacoustic measurements with cochlear implants and transparency with signals of equal intensity (65/65) was feasible (Nair et al. 2017).

By design sounds will always be presented at comfortable levels for the cochlear implant user. It is important to note that if the remote microphone gain is too high then both the sound processor signal and the remote microphone signal will be compressed into the dynamic range of the user. **Too high a remote microphone gain will make environmental sounds softer by comparison and the user may not find this acceptable.**

It is essential to consider are behavioural responses, user perception and to validate with speech in noise testing with and without the remote microphone to assess benefit.

[8] An AB Neptune sound processor can only be checked in the clinic with AB fitting software.

A further note on mixing ratios

The Working Group supports the concept that in an educational setting a mixing ratio of 1:1 (or 50/50) is optimal. However, older users who are confident and comfortable making changes to their processor should have the ability to select different ratios for different environments. For example, a 3:1 or 70/30 mixing ratio would give an enhanced signal-to-noise ratio for the listener; however, their surrounding environment would seem quieter in comparison to the remote microphone (e.g. speech from their peers).

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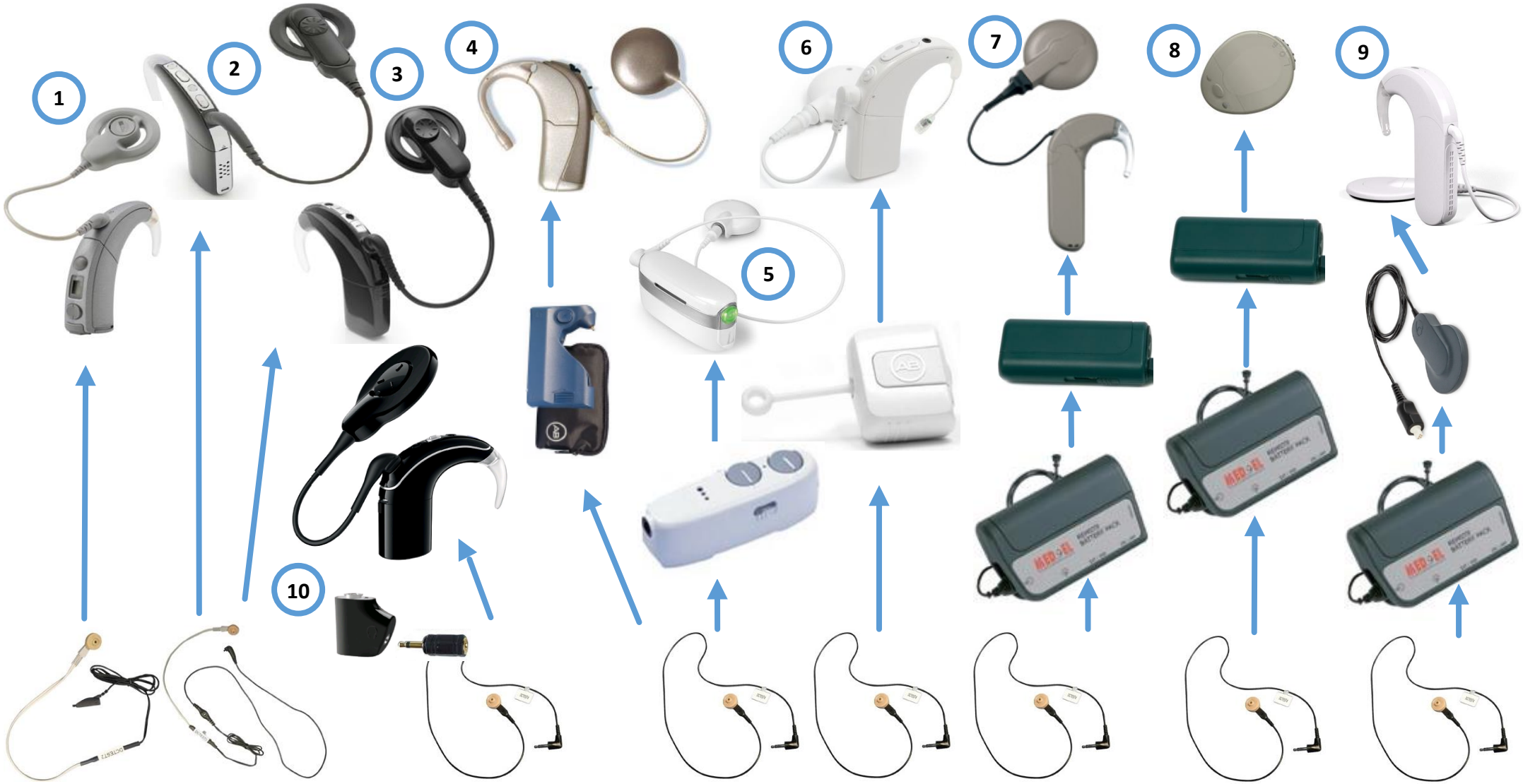
How to create consistent comparative response curves of Cochlear Implant microphones



1. Cochlear Nucleus Freedom – DCTEST2 Lead only. **2.** Cochlear Nucleus 5 CP810 – DCTEST3 Lead only.
3. Cochlear Nucleus 6 CP910 – DCTEST3 Lead only. **4.** Advanced Bionics Harmony – DCTEST4 lead and AB Harmony Listening Check.

5. Advanced Bionics Neptune – DCTEST4 lead and Neptune Connect AB *(AB fitting software required)*.
6. Advanced Bionics Naida Q70, Q90, Naida CI M or Sky CI M – DCTEST4 lead and Naida or Marvel Listening Check.
7. MED-EL OPUS 2 BTE - DCTEST4 lead and Microphone Test Device (MTD) , Mini Battery Pack (MPP) (28cm lead) , MBP MTD Connecting Cable.
8. MED-EL RONDO & RONDO 2 – DCTEST4 lead and Microphone Test Device , Mini Battery Pack with Rondo Connection cable, MBP MTD Cable.
9. MED-EL SONNET & SONNET 2 – DCTEST4 lead and MED-EL Microphone Test Device Kit for SONNET **10**. Cochlear N7 – DCTEST4 Lead & mono adapter

Adapted from an original design by the Ewing Foundation for deaf Children.