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

Checks with auditory implant systems - Draft

Current summary of electroacoustic signal levels

Device	SPL level to processor	SPL level to radio aid
All Advanced Bionics processors	60 dB and 65 dB	65 dB
MED-EL OPUS2 and RONDO	60 dB and 65 dB	65 dB
Cochlear Nucleus 5	60 dB and 65 dB	65 dB

Device	SPL level to processor	SPL level to radio aid
MED-EL SONNET	50 dB and 55 dB	55 dB
Cochlear Nucleus 6 and Nucleus 7	50 dB and 55 dB	55 dB

The most important things to consider are behavioural responses, user perception and to validate with speech in noise testing with and without the radio aid to assess benefit.

Adjust the volume, 'FM advantage' or 'EasyGain' level of the radio aid receiver so that the radio aid response curve matches a sound processor response curve***** to within 2dB for 'transparency' or 'balance'; e.g. an average of the response values at 750Hz, 1kHz and 2kHz or RMS values are within 2dB. Adjusting the receiver should be done preferably by starting at a low volume/gain and then increasing.

***** Signals of equal intensity are likely to provide a match for Phonak Roger design-integrated receivers for cochlear implants (Roger 14, 17, 20 and 21). Other radio aid systems may provide a match with signals of equal intensity. However, as per the original protocol, you may decide to opt for a match to the 5dB lower curve, or between the two. If possible, discuss with the user their preference of set-up; i.e. whether the radio aid response is matched to the lower or higher response of the sound processor.

Device	SPL level to processor	SPL level to radio aid
Bone conduction devices	65 dB	65 dB

Adjust the volume, 'FM advantage' or 'EasyGain' level of the radio aid so that the radio aid response curve matches the sound processor response curve to within 2dB for 'transparency' or 'balance'; e.g. an average of the response values at 750Hz, 1kHz and 2kHz or RMS values are within 2dB. Adjusting the receiver should be done preferably by starting at a low volume/gain and then increasing.

Why still draft status?

It is important that any protocol for completing electroacoustic measures with CI and BCHI and personal radio aid systems is validated. Further research into this field is ongoing but this document sets out the previous UK positon and some interim guidance that builds on from the previous 2008 Good Practice Guide (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.

For these reasons, and to allow further feedback from Implant Centres and professional bodies, the checks with auditory implant systems still have draft status.

Checks with auditory implant systems

As part of the usual setting up procedures for personal radio aid 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 radio aid 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 radio aid systems to individuals with auditory implants - Cochlear Implants (CI[1]) or Bone Conduction Hearing Devices and Middle Ear Implants (Bone Conducting Hearing Implants, BCHI[2]).

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 radio aid user more frequently.

When to fit radio aids with implants?

QS1 considers potential candidacy for radio aid 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

[1] 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 5 October 2017)

[2] https://www.england.nhs.uk/commissioning/wp-content/uploads/sites/12/2013/05/16041_FINAL.pdf (Accessed 5 October 2017)

brain and the user learns to interpret the stimulation as meaningful sound.

There is a natural period of time before radio aids 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 radio aid 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 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[3] in England.

Initial UK studies with cochlear implants used test signals of equal intensity in line with MCHAS FM Advantage procedures[4] 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 5dB less to the CI sound processor and matching the radio aid to this (Harris, 2006; Wood, 2008).

Working Group protocol

[3] http://research.bmh.manchester.ac.uk/mchas/aboutus/guidelines
[4] https://www.connevans.info/image/connevans/fmadvantage.pdf

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 the following 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[5].

Summary of the UK 2008 Good Practice Guidance Protocol

Ensure that the appropriate settings of the sound processor (e.g., programs, telecoil function and audio mixing ratio) are enabled by the Implant Centre/Service and that the radio aid transmitter and receiver 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 radio aid and the whole system combined should be carried out. Electroacoustic testing can then be carried out[6] in quiet conditions with an appropriately calibrated test box with measures recorded in SPL.

SPL levels in the original protocol

- Connect the appropriate test lead (CPG QS 8 Appendix 1) to the sound processor and test box (test chamber levelled as necessary).
- Turn the sound processor on and check it is on the default everyday listening program.
- Place the sound processor in the test box chamber (e.g. in the test/target area and within 2mm if with a reference microphone) and close the lid.
- **To the processor:**
  run a frequency response curve with a digital speech signal or speech-weighted signal at 60dB input.
- Attach the radio aid receiver[7] (if not a loop system)
- Select the radio aid program of the sound processor (if necessary).

[5] https://www.connevans.co.uk/productSearch.do?query=dctest
[6] An AB Neptune sound processor with a Connevans fmGenie system can only be checked in the clinic with AB fitting software.
[7] Older sound processors like the Nucleus ESPrit 3G or Freedom required the sound processor to be turned off before the radio receiver was attached.

- Place the processor to one side on a soft surface or place in a suitable position within the neck loop (if using telecoil).
- Turn on the transmitter (and, if necessary, the receiver)
- Activate verification mode on the transmitter (if possible).
- Place the transmitter appropriately in the test box chamber (e.g. in the test/target area and within 2mm if with a reference microphone) and close the lid.
- **To the radio aid:**
  run a frequency response curve with a digital speech signal or speech-weighted signal at 65dB input.
- Adjust the volume, 'FM advantage' or 'EasyGain' level of the receiver radio aid curve so that the radio aid response curve matches the sound processor response curve to within 2dB for 'transparency' or 'balance'; e.g. an average of the response values at 750Hz, 1kHz and 2kHz or RMS values are within 2dB. Adjusting the receiver should be done preferably by starting at a low volume/gain and then increasing.
- Save, print and share the information.

Updates since 2008

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 57dB SPL and results in compression of the input signal. Front-end compression is also observed in the Nucleus7. Following advice from USAIS and the Ewing Foundation, the test box procedure was adapted to present signals of lower intensity.

The protocol of 60dB SPL to the processor and 65dB SPL to the radio aid was applied to Advanced Bionics, MED-EL OPUS2 and RONDO and the Cochlear Nucleus 5 sound processors and older Cochlear Nucleus sound processors. With the release of the MED-EL Microphone Test Device Kit for SONNET front-end compression was also observed in electroacoustic checks.

So, for Nucleus 6 and 7 processors and the SONNET processor the following applies -

50dB SPL to the processor and 55dB SPL to the radio aid:

As per the previous protocol - ensure that the appropriate settings of the sound processor, radio aid and test box are employed, listening checks have been carried out and that measures are recorded in SPL.

- Connect the appropriate test lead (CPG QS 8 Appendix 1) to the sound processor and test box (test chamber levelled as necessary).
- Turn the sound processor on and check it is on the default everyday listening program.
- Place the sound processor in the test box chamber (e.g. in the test/target area and within 2mm if with a reference microphone) and close the lid.
- **To the processor:**
  run a frequency response curve with a digital speech signal or speech-weighted signal at 50dB input.
- Attach the radio aid receiver (if not a loop system)
- Select the radio aid program of the sound processor (if necessary).
- Place the processor to one side on a soft surface or place in a suitable position within the neck loop (if using telecoil).
- Turn on the transmitter (and, if necessary, the receiver)
- Activate verification mode on the transmitter (if possible).
- Place the transmitter appropriately in the test box chamber (e.g. in the test/target area and within 2mm if with a reference microphone) and close the lid.
- **To the radio aid:**
  run a frequency response curve with a digital speech signal or speech-weighted signal at 55dB input.
- Adjust the volume, ‘FM advantage’ or ‘EasyGain’ level of the receiver radio aid curve so that the radio aid response curve matches the sound processor response curve to within 2dB for ‘transparency’ or ‘balance’; e.g. an average of the response values at 750Hz, 1kHz and 2kHz or RMS values are within 2dB. Adjusting the receiver should be done preferably by starting at a low volume/gain and then increasing.
- Save, print and share the information.

Further work

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

Wolfe & Schafer (2015) suggested that transparency with cochlear implants and radio aids 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).

It is thought that signals of equal intensity will be similarly compressed by Cochlear's ASC so that a signal of 5dB lower to the processor may not be necessary.

The protocols of lower signals, 60dB SPL to CI and 65dB SPL to radio aid, were the results of user feedback in the UK and the subsequent 50dB SPL to CI and 55dB SPL to radio aid was advised due to compression seen in the Cochlear N6 and MED-EL SONNET processors. However, implant processor and radio aid technology has greatly advanced. It is essential that further research is conducted to establish the suitability of signal levels through qualitative methods and behavioural testing.

All current protocols are based on the responses to inputs to the system which are after any signal compression by the radio aid and before any signal compression by the sound processor. Representatives from the UK Children's Radio Aid Working Group have begun to undertake this research by considering the UK 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.

Interim guidance

The Working Group suggests extending testing to the processor by running two processor curves, 5dB apart. A signal at the higher level is presented to the system via the transmitter. Of utmost importance is the perception of the user and speech testing will help evaluate the fitting.

For processors with front-end compression∆ present:

- **To the processor:**
  1) a frequency response curve with a digital speech signal or speech-weighted signal at 50dB input.
  2) a frequency response curve with a digital speech signal or speech-weighted signal at 55dB input.
- **To the radio aid:**
  a frequency response curve with a digital speech signal or speech-weighted signal at 55dB input.

∆ Currently: Cochlear Nucleus 6, Nucleus 7 and MED-EL SONNET.

Otherwise present:

- **To the processor:**
  1) a frequency response curve with a digital speech signal or speech-weighted signal at 60dB input.
  2) a frequency response curve with a digital speech signal or speech-weighted signal at 65dB input.
- **To the radio aid:**
  a frequency response curve with a digital speech signal or speech-weighted signal at 65dB input.

In either case:

- Adjust the volume, 'FM advantage' or 'EasyGain' level of the radio aid receiver so that the radio aid response curve matches a sound processor response curve* to within 2dB for 'transparency' or 'balance'; e.g. an average of the response values at 750Hz, 1kHz and 2kHz or RMS values are within 2dB. Adjusting the receiver should be done preferably by starting at a low volume/gain and then increasing.
- * Signals of equal intensity are likely to provide a match for Phonak Roger design-integrated receivers for cochlear implants (Roger 14, 17, 20 and 21). Other radio aid systems may provide a match with signals of equal intensity. However, as per the original protocol, you may decide to opt for a match to the 5dB lower curve, or between the two. If possible, discuss with the user their preference of set-up; i.e. whether the radio aid response is matched to the lower or higher response of the sound processor. ***It is essential to consider are behavioural responses, user perception and to validate with speech in noise testing with and without the radio aid to assess benefit.***
- Save, print and share the information (QS11).

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

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 radio aid (e.g. speech from their peers).

Signals for BCHI sound processors and radio aids

BCHI signal processing is more conventional and electroacoustic test signals of equal intensity can be used; i.e., 65dB SPL to the processor and 65dB SPL to the radio aid.

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