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Original Article

Bone-Anchored Hearing Aids Fitted According to NAL and DSL Procedures in Adults with Mixed Hearing Loss

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BACKGROUND: Bone-anchored hearing aids represent a valid alternative for patients with conductive/mixed hearing loss who cannot use hearing aids. To date, these devices have given good audiological results, thanks to various fitting prescription programs (i.e., National Acoustic Laboratories and Desired Sensation Level). The aim of this study is to compare 2 types of fitting algorithms (National Acoustic Laboratories and Desired Sensation Level) implemented for bone-anchored hearing devices.

METHODS: We retrospectively enrolled 10 patients followed at our operative unit, suffering from bilateral symmetrical mixed hearing loss and who underwent bone-anchored hearing aid implantation. All patients experienced each prescriptive procedure, National Acoustic Laboratories and Desired Sensation Level, for 7 months (on average), and they were subjected to audiological tests and questionnaires to evaluate the best program.

RESULTS: National Acoustic Laboratories and Desired Sensation Level prescriptions yielded similar results. Desired Sensation Level allowed less amplification of the low frequencies than the National Acoustic Laboratories prescription, and these differences were the only statistically significant. Desired Sensation Level allowed better disyllabic word and sentence recognition scores only in quiet and not in noisy conditions. The subjective questionnaires showed similar results. At the end of the trial sessions, more patients (60%) definitively chose the Desired Sensation Level program for their device. These patients were those with a worse hearing threshold.

CONCLUSION: The 2 prescriptive programs allowed similar results although patients with a worse threshold seem to prefer the DSL program. This is the first evaluation of the 2 prescriptive programs, National Acoustic Laboratories versus Desired Sensation Level, for bone conduction devices available in the literature. Further studies are needed to confirm this initial finding.

KEYWORDS: Bone-anchored hearing aids, hearing loss, middle-ear implants, prescriptive National Acoustic Laboratories, prescriptive Desired Sensation Level

INTRODUCTION

To date, the National Acoustic Laboratories (NAL) and Desired Sensation Level (DSL) procedures have been widely used by clinicians to fit hearing aids. The NAL "family" of fitting methods (NAL, NAL-R, NAL-NL1, and NAL-N2) try to equalize, rather than normalize, loudness relationships across speech frequencies. According to Dillon et al.[1] if all the speech frequencies are amplified so that they are heard equally loud, speech intelligibility is maximized. The NAL methods do not try to preserve or normalize the loudness relationship between speech frequencies; instead, they strive to normalize loudness for the total speech spectrum. On the contrary, the DSL method normally plots its targets in terms of output, not gain. For DSL prescriptions, the output is the sound that is delivered to the eardrum of the listener, while the gain is merely a means to an end. The 2 different procedures have different estimators, with some studies showing a preference for the NAL procedure, while others for the DSL procedure.[2-5]

From the literature data, the DSL prescription seems to better improve the perception of sentences in quiet than the NAL prescription. On the contrary, no significant differences are reported between prescriptions for sentence perception in noise

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and for consonant discrimination in quiet.[6] The impairment level is one of the key factors in choosing the prescription method. Subjective measures in real-life showed that subjects with moderately severe to profound hearing loss required gain and frequency responses, which were closer to the DSL prescription than the NAL prescription.[6]

For sensorineural hearing loss, the 2 prescriptions each have one advantage and disadvantage, both of which allow good results in restoring hearing. On the contrary, subjects with conductive or mixed hearing loss seem to achieve better results with the NAL procedure.[6] The NAL prescription generally activates less than full restoration of the conductive or mixed component, reducing the distortion and improving the understanding of words. With the DSL's general aim of maximizing comfortable audibility, for conductive and mixed hearing losses, the predicted upper limits of comfort (ULC) are increased, which in turn makes the input/output function more linear, applying more gain.[7] The most striking difference in the prescribed insertion gain is not predicted speech intelligibility for average level speech but, rather, loudness. Desired Sensation Level prescribes less loudness than the NAL methods.

In recent years, both NAL and DSL prescriptions, designed for bone conduction devices, have been available for bone-anchored hearing aids.[8] Audiologists and implanted patients can choose between the 2 programs, but the choice of the best prescription is difficult in the case of a single implanted device that transmits the vibration to both ears.

The aim of this study is to evaluate the differences between NAL and DSL to fit bone-anchored hearing aids in implanted patients affected by symmetrical mixed hearing loss.

MATERIALS AND METHODS

The study was developed in our operative unit, as part of routine care. Starting in January 2020, we recalled the last 10 subjects affected by bilateral symmetrical mixed hearing loss who were implanted with bone-anchored hearing aids at our institution, to submit them to a retrospective crossover, 2-period prescription study trial.

The sample was composed of 10 adult patients, 2 males and 8 females, aged between 31 and 78 (mean = 55.77 years, SD = 18.68), all affected by bilateral symmetrical mixed hearing loss as a consequence of otologic surgeries for the treatment of chronic otitis media. No cognitive impairments, motor, neurological, psychological or visual disorders, and/or relevant health problems were present.

All patients were fitted with a percutaneous bone-anchored hearing aid (Ponto 3, Ponto 3 Power, and Ponto 3 SuperPower) implanted behind the worse ear (worse air threshold). All the devices are fully programmable with 15 signal-processing channels and 10 programmable bands and they capture advanced signal processing such as automatic multiband adaptive directionality with split mode and tri-state noise reduction, 4 memory programs, data logging feature, feedback manager, and sound recovery (frequency compression). The implants were all fitted using the NAL program to analyze external sound. After surgery, none of the patients used a hearing aid in the ear contralateral to the bone device.

The 10 subjects enrolled were included in the first trial period. All subjects, already fitted according to the NAL prescriptive procedure for 7 months on average (see the Results section), were submitted to a battery of audiological examinations, including pure tone audiometry, free-field audiometry with and without the device, speech perception test (SPT) and subjective questionnaires, such as the Abbreviate Profile of Hearing Benefit (APHAB)and the speech, spatial, and quality of hearing (SSQ). Pure-tone audiometry was conducted with an Interacoustics Clinical Audiometer AC40. When measuring the hearing threshold, both with headphones and in free-field with and without the device, we assigned a value of 125 dB to any frequency threshold over the maximum output limit of the audiometer (105 dB for 0.25 kHz, 125 dB for 0.5 and 1 kHz, and 120 dB for 2 kHz). Any vibrotactile sensation was excluded. Speech perception was assessed using an SPT in Italian in free field, performed by the same speech therapist in all the patients to avoid bias, with live voice, and without lip-reading. We evaluated the disyllabic word recognition score using lists of 20 disyllabic Italian words at a level of 65 dB. The test was performed both in silence and with background noise, with a signal-to-noise ratio (SNR) +10.

After the tests, the second trial period started, and the prescription was changed to a DSL program. All the patients used the implant with the DSL program for the same length of time that they used the NAL program. Finally, the patients underwent the same battery of audiological examinations and questionnaires. At the end of the trial periods, they could choose the prescription they preferred.

All 10 subjects voluntarily decided to change their prescription procedures from NAL to DSL.

For the statistical analysis, descriptive statistics, means, and standard deviations (SD) were performed. Analysis of variance was evaluated using the one-way ANOVA procedure, with a *P*-value less than .05 chosen for the level of significance. Written informed consent was obtained from all participants who participated in this study.

RESULTS

The patient's hearing threshold levels were measured at 0.25, 0.5, 1, 2, and 4 kHz; the results are shown in Figure 1. The hearing thresholds were the same for the 2 trial periods, which on average lasted 7.7 $\pm$ 3.6 months and 7.1 $\pm$ 2.7 months for the NAL and DSL programs, respectively.

The mean and SD of free-field audiometry of all the subjects without the device were 65 $\pm$ 12.5, 64.4 $\pm$ 14.2, 60.5, $\pm$ 13.3, 57.2 $\pm$ 17.7, and 74.4 $\pm$ 24.7 at 0.25, 0.5, 1, 2, and 4 kHz, respectively. Figure 2 shows the mean and SD of the free-field audiometry for all the subjects with the device fitted with the NAL and DSL programs. The *P*-value of ANOVA for the low frequencies was significant: .001 and .02 for 0.25 and 0.5 kHz, respectively (see Figure 2). The NAL allowed a better threshold at all the frequencies compared to the DSL prescription. Figure 3 presents the frequency-specific ratios for each reviewed study, obtained by dividing the mean "effective gain" by the mean cochlear hearing loss.[9] This ratio was calculated for 0.5, 1, 2, and 4 kHz, separately. The "effective gain" is defined as the cochlear (bone-conduction) thresholds minus the aided thresholds.[9] Also, for this analysis, the differences between the 2 prescriptive procedures at 0.25 and 0.5 Hz were significant, $P = .0006$ and $P = .01$, respectively.

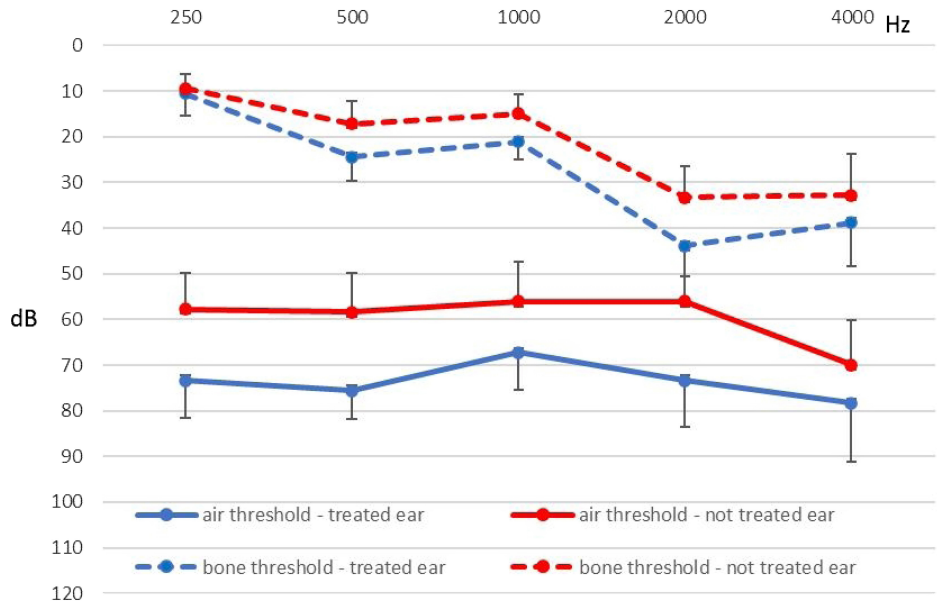

Figure 1. Means with standard deviation for air conduction (AC) and bone conduction (BC) audiometry data for the subject cohort in this study.

Table 1 lists the results of the SPT in the 2-trial periods: the first, when the subjects used NAL and, the second, using the DSL program. Analysis of the 2 SPT did not reveal significant differences.

The APHAB test was carried out by all the subjects. The values of ease of communication (EC), background noise (BN), reverberation (RV), and aversiveness sound (AS) were 4.3, 9.8, 12.3, and 39.1 for the NAL program and 2.3, 9.6, 5.29, and 32.5 for the DSL program, respectively (see Figure 4). The difference between the subgroups was not significant.

The SSQ test for all the patients was analyzed for the 3 subscales (see Table 2). The speech was 7.2 and 7.5 for NAL and DSL, respectively. Spatial was 5.8 and 6.5, and quality of sound was 7.7 and 8.4 for NAL and DSL, respectively. Also, in this case, the differences between the programs were not significant.

At the end of the second trial period, the subjects could choose the prescription they preferred. The DSL program was chosen by 6 out of 10 subjects; the others returned to the previous NAL program. The patients who chose the DSL program had a lower mean hearing threshold than the patients who chose the NAL program (71.3 dB and 60.75 dB, respectively). However, this difference was not statistically significant ($P = .33$).

DISCUSSION

The present study investigates the performance of the NAL and DSL prescriptions utilized for the fitting of a bone-anchored hearing aid

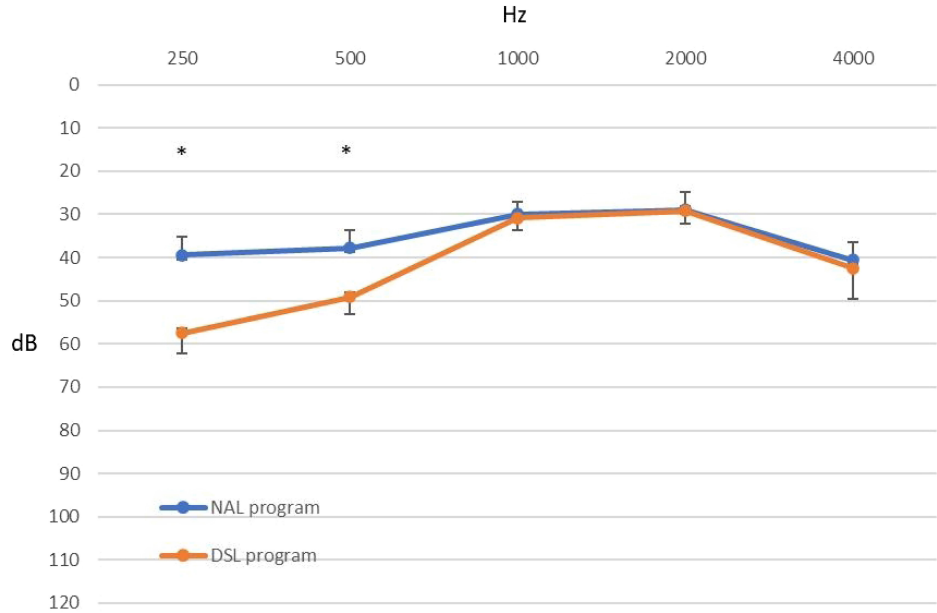

Figure 2. Mean and standard deviation of the free-field audiometry for all the subjects with the device fitted with the NAL and DSL programs. *Statistically significant difference. NAL, National Acoustic Laboratories; DSL, Desired Sensation Level.

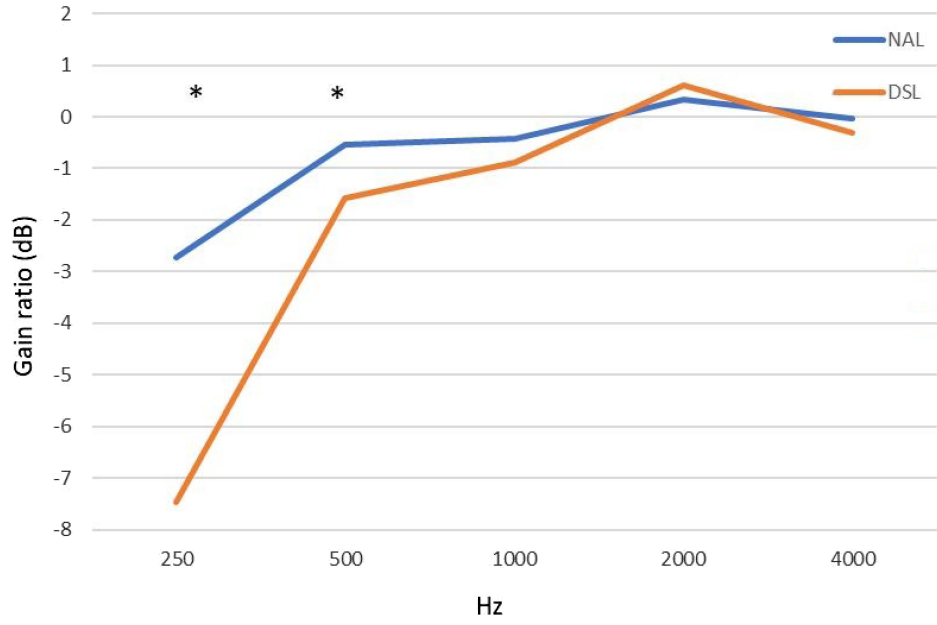

Figure 3. The ratio (mean "effective gain" divided by the mean cochlear hearing threshold) is a function of frequency.[9] *Statistically significant difference.

Table 1. Mean (%) and Standard Deviation of the Disyllabic Word and Sentence Recognition Score in Quiet and in Noise with the NAL and DSL Program

	Quiet			Noise		
	NAL Program	DSL Program	Change (*P*)	NAL Program	DSL Program	Change (*P*)
Disyllables	85 ± 11.4	95 ± 6.3	NS	78.2 ± 19.2	77.5 ± 22.3	NS
Sentences	90.5 ± 14.5	92.7± 10.9	NS	82.8 ± 20.1	83.5 ± 11.9	NS

SD, Standard deviation; NAL, National Acoustic Laboratories; DSL, Desired Sensation Level.

device in a group of implanted patients with bilateral symmetrical mixed hearing loss. This study contributes new objective and subjective data to the performance of the 2 prescriptions for bone conduction implanted hearing aids.

The 2 systems are variously utilized to fit hearing aids. Audiologists and patients may have a preference for one or the other prescription program and there are no universally accepted guidelines for choosing which algorithm.[10,11] Conventional hearing aids have been widely evaluated for the comparative aspects of 2 prescription programs, correlating with the results of hearing threshold, speech perception, the individual anatomical characteristics, and the specific preferences and needs of children, adults, and the elderly.[10-12]

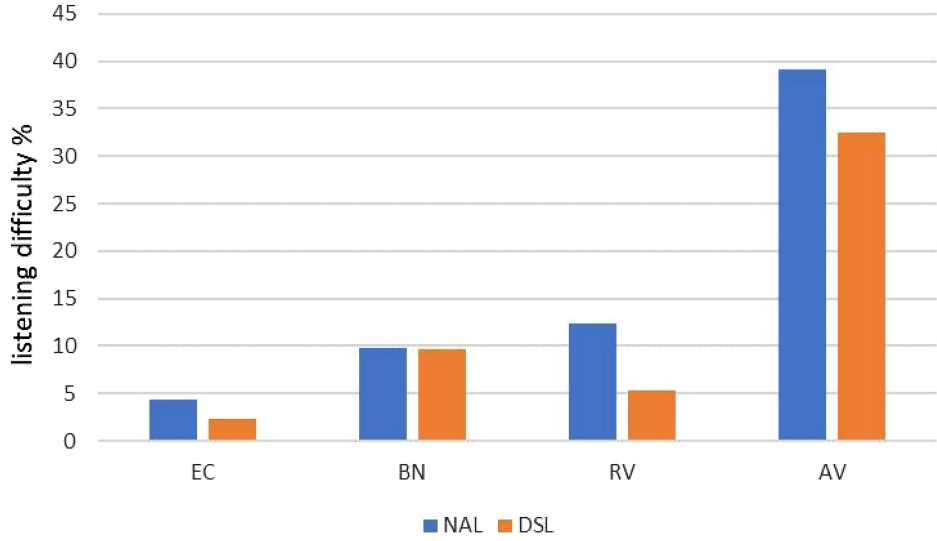

Figure 4. APHAB test for all the subjects, for the NAL and DSL programs. APHAB, Abbreviate Profile of Hearing Benefit; NAL, National Acoustic Laboratories; DSL, Desired Sensation Level.

Table 2. Speech, Spatial, and Qualities Test for the NAL and DSL Programs. Speech, Spatial, and Qualities (SSQ) of Hearing Scale. Mean Score, Standard Deviation, and Range for Each Subgroup, Speech, Spatial, and Qualities Are Shown

	NAL Program	DSL Program	Change (*P*)
Speech	7.2 (SD 3.3, range 4.4-9.4)	7.5 (SD 1.8, range 6.6-9.1)	NS
Spatial	5.8 (SD 3, range 3.8-9.4)	6.5 (SD 2.7, range 4.8-9.4)	NS
Qualities	7.7 (SD 0.8, range 6.1-9.7)	8.4 (SD 1.6, range 7-9.8)	NS

SD, Standard deviation; NS, Non-Significant; NAL, National Acoustic Laboratories; DSL, Desired Sensation Level.

The 2 prescription programs yield similar results for the treatment of sensorineural hearing loss.[11] The differences that do exist between the prescribed insertion gains give rise to only small differences in predicted speech intelligibility in quiet. However, DSL seems to produce better results than the other and, moreover, the DSL program is preferable in cases of severe hearing loss.[11] Similar results are evident for bimodal users with moderate-to-severe hearing loss and hearing aid experience contralateral to the implanted side with a cochlear implant.[13] The majority of users accept both gain prescriptions with little or no adjustment from the default gain. For experienced users, conversion of the hearing aid prescription to DSL may enhance speech perception. An increased mid- and high-frequency hearing aid gain is beneficial for bimodal speech perception.[13]

On the contrary, DSL provides much less insertion gain than NAL for conductive and mixed hearing losses.[7,11] In detail, the NAL procedure has the principle of applying its sensorineural loss rule to the bone conduction thresholds and then applying three-quarters of the air-bone gap to determine insertion gain. For the NAL procedure, not all of the conductive component is compensated, so as not to saturate the device and avoid distortion.[14] The DSL procedure may not implement the 75% air-bone gap plus bone conduction threshold approach. While the DSL, with the general aim of maximizing comfortable audibility and not surpassing the ULC, generally results in less amplification than the NAL procedure. The problem for conductive and mixed hearing loss is to allow greater amplification without distortion and only the NAL procedure seems able to do it.

All these considerations become even more intricate when the 2 prescriptive procedures are utilized to fit bone conduction hearing aids. In that case, the sound signal goes through the bone directly to the inner ear, skipping the middle ear, and generally, the device is only one for both ears.[15] Moreover, unlike air conduction hearing, where the hearing aid has only a small mass, low-impedance eardrum to vibrate, bone conduction devices are coupled to a large head with high impedance. Often, the maximum power output of bone conduction devices remains lower than the loudness discomfort levels of most bone conduction users.

For bone conduction hearing aids, the detection threshold measured is made in situ through the abutment of the device. The in situ threshold is transformed from nominal dial level to force levels on the skull simulator, and finally, the Real Head to Coupler Difference (RHCD) is evaluated.[8] Real Head to Coupler Difference is similar to the Real Ear to Coupler Difference and is a frequency-specific difference between the force levels on the skull and the force level in a simulator. The RHCD is the value that allows calculating the force level of stimulation on the abutment device and is utilized to compute the prescription for outputs within the NAL and DSL algorithms.

As for conventional hearing aids and also for bone conduction devices, the 2 prescriptive programs aim to maximize speech intelligibility in the case of the NAL, whereas the DSL aims to normalize loudness. Desired Sensation Level prescribed a higher overall gain than did NAL. In particular, DSL improves the high frequencies, which are modified less by the NAL program. On the contrary, the low frequencies are improved only by the NAL program.

In our series, ten patients were evaluated alternatively with the 2 bone prescriptions, NAL and DSL, on the same percutaneous bone device. These prescriptions yielded generally similar results. DSL had less amplification of the low frequencies than the NAL prescription, and these differences were statistically significant. Moreover, DSL seemed to allow better disyllabic word and sentence recognition scores in quiet. On the contrary, in noisy conditions, the good performances of the DSL collapsed due to the difficulties in identifying words at low frequencies. Subjective questionnaires, the APHAB and SSQ, showed similar results, even if at the end of the trial sessions, more patients (60%) preferred the DSL program. The current findings suggest that the choice of prescription should be guided by the acceptability of the loudness sensation resulting from the application of each prescription, as both appear to provide similar speech intelligibility.

CONCLUSION

This is the first comparison between 2 prescriptive programs, NAL and DSL, for bone-anchored hearing devices in the available literature. In our study, the DSL seems to offer better results than the NAL prescriptive program, and more patients preferred it.

More studies and larger samples are needed to add more evidence and to evaluate the variables that could influence the results: percutaneous or transcutaneous devices, symmetrical or asymmetrical hearing loss (generally only 1 device is implanted for both ears), and the conductibility of the bone.

Ethics Committee Approval: N/A

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – L.B., F.F.; Design – R.C., L.B.; Supervision – M.G. F.F.; Funding – S.B.; Materials – F.L.; P.P.; Data Collection and/or Processing – G.G., R.C.; Analysis and/or Interpretation – L.B., M.G.; Literature Review – F.L., G.F.; Writing Manuscript – L.B., F.F.; Critical Review – F.F., G.F.

Declaration of Interests: The authors have no conflict of interest to declare.

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