






# Frequency Modulation System and Bone Conduction Hearing Aid: Electroacoustic Verification

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## Abstract

**Introduction** A protocol has not yet been developed to perform electroacoustic measurements and behavioral tests to fit the frequency modulation (FM) system in bone conduction hearing aid (BCHA) users. Electroacoustic verification, with “FM transparency” achieved, ensures user audibility of FM transmitter and hearing aid signals.

**Objective** To propose and validate a protocol for electroacoustic verification of the FM system coupled to the BCHA.

**Method** Twenty-four sets of FM system and BCHA were submitted to electroacoustic verification, using a receiver and a plastic adapter to connect the BCHA to a 2cc coupler in the hearing instrument analyzer. The measurements were performed in the acoustic box, at 65 dB sound pressure level (SPL), with International Speech Test Signal (ISTS), first to the BCHA microphone and then to the FM system microphone, to determine the transparency, in which equivalent inputs for both microphones result in equivalent outputs. The FM gain or volume has been adjusted to try to gain transparency for the outputs of the two input devices.

**Results** Transparency was achieved for all sets evaluated, but in some combinations, adjustments to the FM receiver gain over the manufacturer’s default setting were required.

**Conclusion** The proposed protocol proved to be effective for the electroacoustic verification of the FM system coupled to the BCHA.

## Keywords

- ▶ microtia
- ▶ hearing aids
- ▶ hearing loss

## Introduction

Congenital ear malformations cause hearing difficulties, interfering with the development of speech and language skills and, consequently, impairing the social, emotional, cognitive, and academic development of the child.<sup>1</sup>

The aim of amplification is to provide the child with hearing loss the opportunity to have access to the hearing environment and especially the speech. In children with permanent conductive hearing loss, when anatomically possible (anatomy of the external ear and external auditory

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canal sufficient to retain the earmold and the hearing aid), the fitting of individual hearing aids by air conduction should be prioritized. When the anatomy is insufficient (significant anatomical malformations, chronically draining ears, etc.), the most appropriate option is bone conduction hearing aid (BCHA) fitting.<sup>2</sup>

A BCHA is an external device consisting of a microphone and an amplifier, a wire, and a vibrator, mounted on a metal or an elastic band, which will provide the pressure necessary to transmit the amplified acoustic signal (vibration) to the skull.<sup>2</sup>

A previous study<sup>3</sup> demonstrated the benefit of BCHAs for acoustic signal perception and speech recognition in noise in individuals with congenital ear malformations. The study participants were also satisfied with the devices, despite the numerous disadvantages cited in the literature, such as headaches caused by metal band pressure on the mastoid, skin irritation from vibrator and metal band contact, poor sound quality, dissatisfaction with the aesthetic visibility of the components, as well as the negative psychosocial impact by the use of the apparatus.

Bone conduction amplification can also be provided by an osteo-anchored device called an osteo-anchored hearing aid or a bone-anchored hearing aid whose vibrator is attached to a surgically implanted support. This device causes less discomfort than traditional BCHAs because it eliminates metal headband pressure, reduces acoustic feedback and distortion, and improves hearing at higher frequencies since bone conduction occurs more directly.<sup>4</sup> In Brazil, the Ministry of Health<sup>5</sup> approved the use of osteo-anchored hearing aids for children older than five years; in younger children, the bone conduction amplification can be accomplished by means of an elastic band (Softband).<sup>1,2,5</sup>

However, not all individuals with congenital ear malformations are candidates for surgery, and not all centers specializing in the rehabilitation of hearing impaired individuals have this feature.

Thus, BCHAs should be considered as an option when selecting and indicating the electronic sound amplification device for this population.

Children have higher hearing demands than adults to understand speech, particularly when listening is difficult (reduced speech signal intensity, noisy and/or reverberant environment). Improved audibility is required to provide better speech understanding, whether through increased speech signal strength, increased signal-to-noise ratio, or improvements in the listening environment. Thus, in the classroom, strategies or devices to address the effects of distance and reverberation should be included to optimize the use of hearing aids.<sup>2</sup>

Any child with a hearing impairment is a candidate for hearing assistance resources, which may include preferred classroom seating or a frequency modulation (FM) system, in which the teacher uses a microphone/transmitter and the child a receiver, coupled with his hearing aid.<sup>1</sup>

The purpose of fitting the FM system is to enable access to speech information when noise, distance, and reverberation interfere with speech signal pickup. This access is guaranteed by the improved signal-to-noise ratio that the FM system provides. The signal captured by the transmitter microphone

is sent to the receiver, connected to the hearing aid with a gain advantage in the captured signal.<sup>6</sup> The recommendation is that the FM system can provide a 10 dB advantage between the FM signal when compared with the signal captured by the hearing aid microphone.<sup>7,8</sup>

The FM signal perceived by the user is dependent on the amplification characteristics previously programmed in the hearing aid. In the ideal listening situation, when an FM system is connected to the amplifier device, the output response characteristics of the device should be maintained. This means that when connecting a receiver to the hearing aid, no modification in the amplification output response should be made or perceived by the user.<sup>7</sup>

The evaluation of the benefits of fitting an assistive technology, such as the FM system, in hearing aids or cochlear implants (CIs), should be composed of subjective and objective procedures.<sup>6</sup> As subjective assessment methods, there are speech in noise tests and questionnaires. In the objective evaluation, the electroacoustic verification, obtaining the "FM transparency" allows to assure audibility of both the FM transmitter signal and the air-conduction hearing aid signal consistently for the user and to make sure that the amplification offered by the hearing aid does not change when entering the FM system signal.<sup>7,9</sup>

*"Transparency is achieved when the 65 dB SPL input to the FM microphone produces a result equal to the 65 dB SPL input to the microphone of the individual sound amplifier".<sup>7,8</sup>*

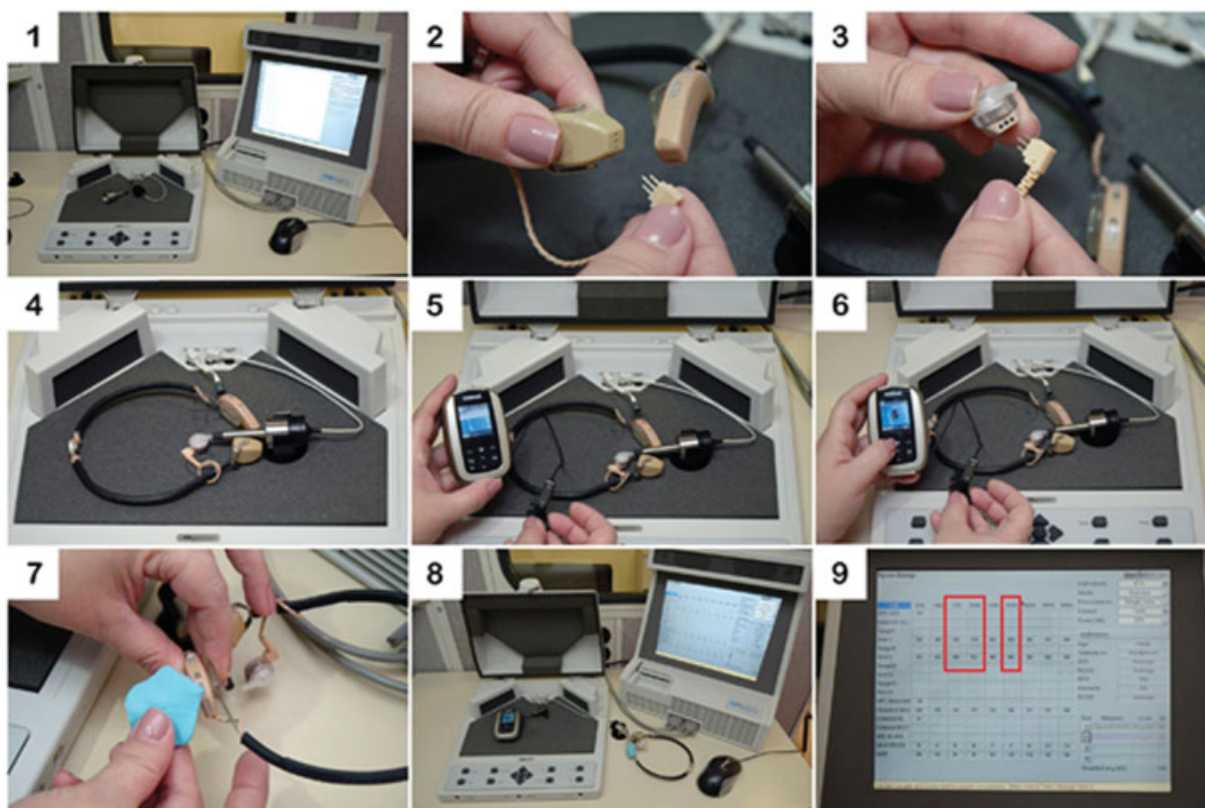
However, a protocol for the electroacoustic verification of the BCHA coupled FM system has not yet been developed. Thus, the objective of this study was to propose and validate a protocol for electroacoustic verification of the FM system, coupled to BCHAs.

## Method

This is a descriptive cross-sectional study, developed in a hearing health service of the Brazilian Unified Health System. Electroacoustic Verification Protocol:

The electroacoustic verification protocol used in the present study was developed based on the recommendations of the American Academy of Audiology.<sup>7</sup> It was necessary to use a plastic adapter and a 3-input receiver to couple the BCHA to the HA-1 coupler of the Verifit/Audioscan, Verifit (Division of Etymonic Design Incorporated, Ludwig St. Dorchester, ON, CA), and the protocol was applied as described below and as shown in ►Fig. 1:

1. Calibrate the equipment Audioscan, Verifit (Division of Etymonic Design Incorporated, Ludwig St. Dorchester, ON, CA) with the HA-1 coupler;
2. Disconnect the wire that connects the hearing aid to the bone vibrator;
- 3,4. Connect the wire (hearing aid) to the HA-1 coupler inside the test box, using a receiver and a plastic adapter;
5. Turn on the FM transmitter, checking its synchronization with the FM receiver;



**Fig. 1** Step-by-step for the electroacoustic verification—bone conduction hearing aid and FM system.

6. Set the microphone of the transmitter to the “mute” function; if this option is not available, seal it with dough; Draw curve 1 for a 65 dB SPL input (stimulus: International Speech Test Signal [ISTS]);
7. Seal the hearing aid’s microphone;
8. Remove the BCHA (+ receiver + plastic adapter) still connected to the HA-1 coupler and the test microphone out of the test box and turn on the microphone of the FM transmitter and place it in the test box; Draw curve 2 under the same conditions as curve 1;
9. After performing both measurements, the results in dB SPL should be noted, and the average of the output differences calculated at the 3 frequencies of interest (750, 1,000, and 2,000 Hz).

Transparency is achieved when the average of the hearing aid + FM condition is equal to or less than 3 dB of the average of the hearing aid-only condition. When the difference is greater than 3 dB, the receiver gain should be adjusted and measurements repeated.

#### Procedures

Three models of BCHAs: Phonak, Naída IUP, Naída ISP and Naída S ISP (Sonova, Stäfa, CH) with headband, wire, and bone vibrator are programmed, with the prescriptive rule DSL v5.0<sup>2</sup> being adopted to ensure that the signal processing of the hearing aid has been adjusted to provide audibility and output response that are appropriate to the user’s needs for different

input signal levels, as well as to receive FM signal (FM + M initial program option, automatic).<sup>7</sup>

Three FM transmitter models: Oticon, T31 Amigo, (Oticon, Smorum, DK), Phonak, SmartLink and Inspiro Premium (Sonova, Stäfa, CH), three FM receiver models: Oticon, R2 (Oticon, Smorum, DK), Phonak, ML10i and ML11i (Sonova, Stäfa, CH), and two shoe models: Phonak, AS10 and AS11 (Sonova, Stäfa, CH), which were combined, according to ▶ **Table 1**, totaling 24 sets of BCHAs and FM systems were submitted to the electroacoustic verification protocol.

In all 24 sets evaluated, it was possible to fit the FM receiver via direct audio input of BCHAs; In 13 sets (Phonak, FM Systems - Sonova, Stäfa, CH), it was possible to fit the specific receiver and in 11 sets (Oticon FM Systems - Oticon, Smorum, DK) it was necessary to use a shoe and the universal receiver. The FM systems were initially programmed according to the standards established by the manufacturers, adopting the 0 dB gain for Phonak devices<sup>10</sup> and +8 dB for Oticon.<sup>11</sup>

For the various measurements, BCHAs and FM systems were placed inside a sound attenuation box consisting of a foam-lined plastic box. To ensure repeatability of the electroacoustic verification protocol, each measurement was performed at least twice. The FM receiver gain was adjusted to try to achieve transparency for the outputs of both input devices. The Amigo T31 receivers of the Oticon brand have a gain adjustment range of 30 dB. The default position is +8 dB. This means that the receiver gain can be increased by 22 dB and decreased by 8 dB.<sup>11</sup>

**Table 1** Bone conduction hearing aids and frequency modulated systems (transmitters, receivers, and audio input shoes) submitted to the electroacoustic verification protocol

N = 24	Bone conduction hearing aids	Transmitters	Receivers	Audio input shoes
2	Naída I UP (Phonak)	SmartLink (Phonak)	ML 10i (Phonak)	—
3	Naída I SP (Phonak)	SmartLink (Phonak)	ML 11i (Phonak)	—
1	Naída I UP (Phonak)	Inspiro P (Phonak)	ML10i (Phonak)	—
3	Naída I SP (Phonak)	Inspiro P (Phonak)	ML 11i (Phonak)	—
4	Naída S ISP (Phonak)	Inspiro P (Phonak)	ML 11i (Phonak)	—
4	Naída I UP (Phonak)	T31 (Oticon)	R2 (Oticon)	AS10 (Phonak)
2	Naída I SP (Phonak)	T31 (Oticon)	R2 (Oticon)	AS11 (Phonak)
5	Naída S IS (Phonak)	T31 (Oticon)	R2 (Oticon)	AS11 (Phonak)

All electroacoustic measurements were performed with Audioscan, Verifit equipment (VF-1) and HA-1 coupler, with the speech stimulus ISTS at 65 dB SPL.

Statistical analysis was performed for all models and brands of BCHAs, FM transmitters, and receivers used in this study. The comparison of the transparency results between different brands and models was performed by the analysis of variance (ANOVA) method, and the comparison from the transparency results between BCHA-only and BCHA plus FM was performed using the paired *t*-test.

## Results

Transparency was achieved for all combinations (100%) of BCHAs and FM systems of this study, as shown in ►Table 2. Some combinations of BCHAs and FM systems from different manufacturers (\*) required gain adjustments of the FM receiver (reduction) over the manufacturer's default setting. To adjust the gain of the R2/Oticon receiver, the T31 Amigo/Oticon transmitter was used, and the adjustment ranged from +8 to 0 dB, and, after such adjustment, the transparency was reached.

There was no significant difference in the comparison of transparency results between models of BCHAs ( $p = 0.780$ ), as shown in ►Fig. 2.

There was also no statistical difference in the comparison of transparency results between FM system models ( $p = 0.764$ ), according to ►Fig. 3.

## Discussion

The ability to fit the FM receiver via direct audio input to the hearing aids results in a listening condition for the patient that combines the operation of two microphones, one local (from the hearing aid) and one remote (from the FM transmitter). This combination allows the patient to perceive ambient sounds and monitor their own voice while consistently listening to the main speaker's voice picked up by the FM transmitter microphone.<sup>7</sup>

Considering this, the objective of the electroacoustic verification of the FM system is to ensure that, from an

electroacoustic point of view, both the signal perceived by the hearing aid microphone and the signal provided by the FM system provide audibility for the entire spectrum of speech sounds without distortion.<sup>8,12</sup>

In the present study, despite the adaptations and the need for adjustments in receiver gain and repetition of measurements, it was observed that electroacoustic verification is a simple, fast, and effective process, as mentioned in the guidelines available in the literature, to perform these measurements.<sup>7,9</sup> In devices in which a specific FM receiver was used, that is, a receiver from the same manufacturer of the BCHA, there was no need to adjust the gain. In 45% of the devices that required the use of a shoe and the universal FM receiver, that is, the receiver is made by a different manufacturer than the one of the BCHA, it was necessary to adjust the gain of the device.

In their study,<sup>13</sup> in the electroacoustic evaluation of the FM system coupled to the Nucleus 5 speech processor, the authors achieved transparency in the 7 (100%) cases evaluated with +2 dB FM gain, without the need for further adjustment since all FM receivers coupled to the Nucleus 5 speech processor were specific (ML14i).

In another study<sup>14</sup> that combined 4 transmitters and 4 receivers for transparency assessment with the Nucleus 5 speech processor, the gain settings required to achieve transparency were highly variable. The authors justified the need for gain adjustment by the fact that they used a universal receiver (MLxi), which requires an adapter (shoe) for connection to the CI.

Other researchers,<sup>13,14</sup> when performing electroacoustic measurements on CI-coupled FM systems, achieved transparency for most combinations of CI and FM, but adjustments in FM gain or volume relative to the manufacturer's default setting were necessary.

Objective verification measures are part of the hearing aid fitting protocols, both for the pediatric population<sup>2</sup> and for adult and elderly patients. In children, the commitment to ensure quality of audibility is even greater, regardless of their stage of development. When children get to school age, the ability to hear and understand verbal information is critical to classroom learning.<sup>12</sup> Thus, Thibodeau and Wallace<sup>15</sup> emphasize the importance of performing electroacoustic verification of assistive

**Table 2** Transparency results—difference between bone conduction hearing aids and frequency modulation systems

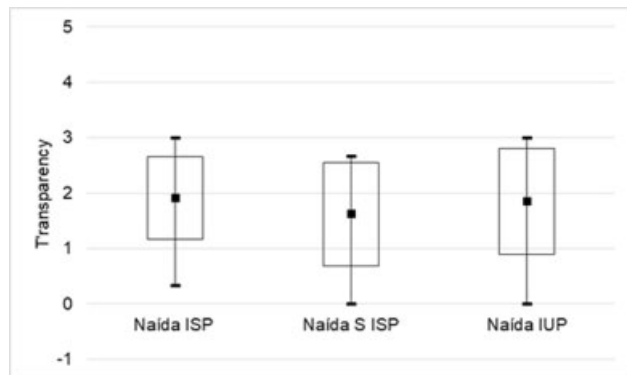
N = 24	BCHA/BCHA+FM	TRANSPARENCY				Difference BCHA/BCHA+FM
		750	1,000	2,000	Mean	
1	Naída I UP	101	96	90	95.66	1.67
	Smartlink + ML 10i	102	98	92	97.33	
2	Naída I UP	76	72	76	74.66	2.67
	Smartlink + ML 10i	80	75	77	77.33	
3	Naída I SP	72	65	63	66.66	3
	Smartlink + ML 11i	75	69	65	69.66	
4	Naída I SP	83	78	77	79.33	2
	Smartlink + ML 11i	85	80	79	81.33	
5	Naída I SP	83	74	75	77.33	2
	Smartlink + ML 11i	85	77	76	79.33	
6	Naída I UP	77	74	71	74	1.67
	Inspiro P + ML10i	73	72	72	72.33	
7	Naída I SP	81	73	72	75.33	1.67
	Inspiro P + ML 11i	79	73	69	73.66	
8	Naída I SP	79	75	76	76.66	2
	Inspiro P + ML 11i	81	77	78	78.66	
9	Naída I SP	81	77	76	78	2
	Inspiro P + ML 11i	84	78	78	80	
10	Naída S ISP	88	85	84	85.66	1.33
	Inspiro P + ML 11i	87	86	86	86.33	
11	Naída S ISP	78	75	74	75.66	2.34
	Inspiro P + ML 11i	81	78	75	78	
12	Naída S ISP	78	71	70	73	2
	Inspiro P + ML 11i	79	73	73	75	
13	Naída S ISP	86	84	82	84	0
	Inspiro P + ML 11i	85	85	82	84	
14	Naída I UP	81	75	73	76.33	0
	T31 + R2+ AS10	81	74	74	76.33	
15*	Naída I UP	80	75	77	77.33	3
	T31 + R2+ AS10	83	78	80	80.33	
16*	Naída I UP	96	86	75	85.66	2
	T31 + R2+ AS10	99	88	76	87.66	
17	Naída I UP	83	74	75	77.33	2
	T31 + R2+ AS10	85	77	76	79.33	
18	Naída I SP	98	90	88	92	0.33
	T31 + R2+ AS11	98	90	89	92.33	
19*	Naída I SP	89	83	77	83	2.33
	T31 + R2+ AS11	91	86	79	85.33	
20	Naída S ISP	88	80	86	84.6	1
	T31 + R2+ AS11	90	82	85	85.6	
21*	Naída S ISP	94	86	78	86	2.66
	T31 + R2+ AS11	95	88	83	88.66	

(Continued)

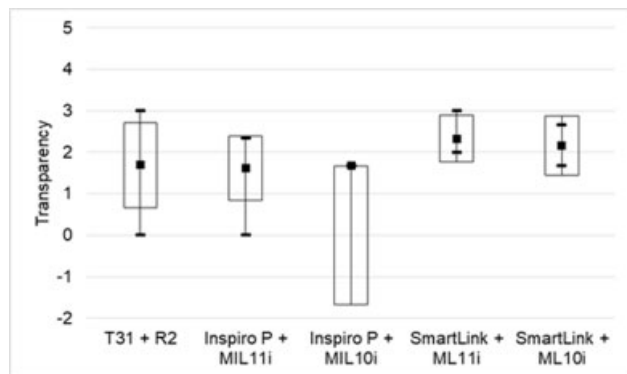
**Table 2** (Continued)

N = 24	BCHA/BCHA+FM	TRANSPARENCY				Difference BCHA/BCHA+FM
		750	1,000	2,000	Mean	
22*	Naída S ISP	87	82	84	84.33	2.67
	T31 + R2+ AS11	89	85	87	87	
23	Naída S ISP	83	80	72	78.33	2
	T31 + R2+ AS11	85	82	74	80.33	
24	Naída S ISP	68	62	56	62	0.66
	T31 + R2+ AS11	69	63	56	62.66	

Abbreviations: FM, frequency modulation; BCHA, bone conduction hearing aid.



**Fig. 2** Comparison of transparency results between bone conduction hearing aid models (analysis of variance).



**Fig. 3** Comparison of transparency results between FM system models (Variance Analysis).

technology devices, such as the FM system, to ensure that they fulfill their purpose of favoring the signal-to-noise ratio.

In future studies, subjective evaluation (speech in noise tests and self-assessment questionnaires) may provide new information on the benefit and satisfaction of users of these devices.

## Conclusions

The electroacoustic verification protocol proposed in this study proved to be effective and allowed the electroacoustic verification of the FM system coupled to the BCHA. The

protocol may be used in new research and clinical practices, provided the need to adjust the gain/volume of the FM system is considered, especially when the evaluated set is composed of devices from different manufacturers. The behavioral measures suggested by the American Academy of Audiology<sup>7</sup> should also be advocated to ensure proper adjustment of the FM system to BCHAs.

### Conflict of Interests

The authors declare that there is no conflict of interests.

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