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1 **AUDIOLOGICAL RESULTS AND QUALITY OF LIFE OF SOPHONO**
2 **ALPHA 2 TRANSCUTANEOUS BONE-ANCHORED IMPLANT USERS**
3 **IN SINGLE-SIDED DEAFNESS**

4 **RUNNING TITLE: SOPHONO ALPHA 2 IN SSD**

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4 their research. Deborah Bernou works as biomedical engineer for Collin Ltd, France, a local
5 distributor of Alpha system.

6

1 **ABSTRACT**

2 Single-sided deafness (SSD) represents one of the most difficult audiological condition to
3 rehabilitate. The aim of this prospective study was to evaluate the audiological benefits and
4 the quality of life when upgrading to Sophono Alpha 2[®] (Boulder, Colo., USA) external
5 processor, patients affected by SSD previously users of Alpha 1[®]. Nine patients have been
6 included. They underwent physical examination, free-field speech audiometry at 40dB and 60
7 dB, hearing in noise test (Hirsch's test and squelch test), Glasgow benefit inventory (GBI)
8 questionnaire, and patient's satisfaction specific questionnaire with Alpha 1[®]. Afterwards, the
9 Alpha 2[®] external processor was delivered to all patients and the above mentioned protocol
10 was repeated after 1 month with the Alpha 2[®]. A statistically significant improvement was
11 found in the speech discrimination score at 40 dB and in the squelch test when using the
12 Alpha 2[®] external processor compared to the Alpha 1[®]. Concerning clinical tolerance, the
13 specific questionnaire and the GBI, the differences were not significant. The new Alpha 2[®]
14 external processor represents a safe and effective device for the rehabilitation of SSD and
15 there is an audiological benefit from upgrading to Alpha 2[®] external processor patients
16 previously users of the Alpha 1[®]. The improvement in the quality of life is similar to other
17 bone-anchored hearing devices.

18 **Keywords:** single-sided deafness, transcutaneous bone-anchored hearing device, Hearing aids,
19 bone conduction, implantable hearing aids, hearing loss

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INTRODUCTION

Single sided deafness (SSD) affects the quality of life of the patients, since they experience discomfort in difficult situations such as hearing in noise or localizing the sound [Douglas et al., 2007]. The loss of hearing in one ear suppresses the interaural time and sound level differences that are responsible of localization [Kitterick et al., 2014]. Patient affected by SSD also show the effect of the acoustic shadow of the head [Carlile, 2006] which is the cause of these difficulties [Van Wanrooij, and Van Opstal, 2004]. Finally, listening to sounds coming from impaired side is also challenging for these patients.

Many studies have been carried out in order to define which was the optimal treatment for this pathological condition. Contralateral rerouting of signal (CROS) hearing aids [Finbow et al., 2015; Bosman et al., 2003; Hol et al., 2005; Wazen et al., 2003], and percutaneous bone-anchored hearing devices [Faber et al., 2013; Zeitler et al., 2012; Stewart et al., 2011; Martin et al., 2010] have been proposed for the rehabilitation of SSD with different results. More recently, cochlear implant has been suggested for the rehabilitation of SSD [van Zon et al., 2015; Erbele et al., 2015; Arndt et al., 2011; Vermeire, and Van de Heyning, 2009].

The Sophono Alpha[®] system (Sophono, Boulder, Colo., USA) is a transcutaneous bone conductive hearing device: the major advantage of this system, compared to the percutaneous ones, is the presence of the intact skin that dramatically reduced the skin related complications [Wazen et al., 2008]. The use of Alpha 1[®] system has already been described for conductive or mixed hearing loss, in adults and in children [Sylvester et al., 2013; Escorihuela-García et al., 2014; Siegert, and Kanderske, 2013; Hol et al., 2013; Magliulo et al., 2014; Denoyelle et al., 2013]. The first prospective clinical study comparing the Alpha 1[®] system and CROS hearing aids in SSD has been recently published [Leterme et al., 2015]. Authors showed that the Alpha 1[®] was preferred to CROS in 72% of patients and that the hearing performance

1 were significantly improved when using the Alpha 1[®] system compared to unaided condition,
2 whereas there were not statistically significant differences when comparing the audiological
3 outcomes of the 2 devices.

4 Recently, the new Sophono Alpha 2[®] external processor has been released: the main
5 differences between the Alpha 1 and the Alpha 2 are the following:

- 6 - A more square and little shape (Fig. 1A and 1B)
- 7 - The presence of 8 digital channels (instead of 4) with 8 programmable settings to
8 facilitate program changing in different environments
- 9 - The presence of 2 microphones (instead of 1 omnidirectional); the first one is
10 directional and the second is omnidirectional
- 11 - Transcutaneous energy transmission technology that should allow obtaining a
12 functional gain of 30 dB by optimizing the mechanical impedance close to skin
13 impedance. It uses an impedance adaptation achieved by a design of the device and the
14 implemented force transducer that decreases the impedance over the relevant range for
15 speech recognition to the impedance of the skin. This is achieved by two resonance
16 frequencies close to each other in the relevant range flattening the transfer barriers
17 through the skin and matching the resonance behaviors of the device and the skin.

18 The aim of this prospective clinical study was to analyze the audiological performance and
19 quality of life (QOL) of patients affected by SSD previously users of Alpha 1[®] external
20 processor, when upgrading them to the new Alpha 2[®] external processor.

21

1 MATERIALS AND METHODS

2 This prospective clinical study was authorized by the hospital ethical committee and all
3 patients gave the written consent for the use of their clinical data. Collin[®] Ltd. (Bagneux,
4 France), local distributor of Alpha system, supported this study by providing the Alpha 2[®]
5 external processor to all patients.

6 The Sophono Alpha[®] system consists in one external processor and one implantable twin
7 magnet (Fig. 1C). The external processor contains a bone conductive oscillator which is
8 mounted on two external magnets. The implantable twin magnets are encapsulated in a
9 titanium case which is fixed to the skull with five little arms.

10 Nine patients were included in this protocol (Tab. 1). All patients had been using the Alpha 1[®]
11 system for at least 1 year. ~~There were 5 males and 4 females. The mean age was 50 ± 9.9
12 years (mean \pm SD, range 40/65 years); the right side was involved in 5 cases, the left side in 4
13 cases. The etiology of unilateral hearing loss was vestibular schwannoma surgery (22%),
14 sudden sensorineural hearing loss (22%), chronic otitis (11.2%) with ipsilateral profound
15 hearing loss, head trauma (11.2%), ototoxicity (11.2%), mumps (11.2%), congenital (11.2%).
16 The mean air conduction threshold (mean of the frequencies 500, 1000, 2000 and 4000 Hz) of
17 the contralateral ear was 21 ± 9 dB and the bone conduction threshold was 14 ± 8.6 dB (Tab.
18 1).~~

19 At the first visit, a physical examination of the skin over the implant was performed (normal
20 or hyperemic). The strength of the magnet, ranging from 0 to 7 was noted. The strength of the
21 magnet was the lowest strength that allowed the uncoupling of the external device when a
22 strength ranging from 1 and 1.5 N was applied with a specific tool. The total hour of wearing
23 the external processor per day was analyzed, as well as the regularity of wearing the external
24 processor (everyday or occasionally in particular situation as in noisy environment, in social
25 activities etc.).

1 **Audiological tests**

2 All tests were performed in an audiometric insonorized room. The mean air conduction (AC)
3 and bone conduction (BC) thresholds were calculated using headphone (mean of the
4 frequencies 500, 1000, 2000 and 4000 Hz). In the free-field test as well as in noise, 3 speakers
5 were used placed at 1 m from the patient (in front, left and right ear)

6 Free-field speech audiometry in quiet using French Lafon's monosyllabic words delivered at
7 40 and 60 dB to the deaf side was performed in unaided (UA) condition and without Alpha 1[®]
8 device. The percentage of correct responses was noted.

9 In noise, two tests were performed depending of the respective presentation of the noise and
10 stimulation: The Hirsch's test [Hirsch, and Anderson, 1980] (white 65 dB noise presented
11 frontally and French Lafon's monosyllabic words of increasing intensity delivered to the deaf
12 side) was performed in UA condition and without Alpha 1[®] and the speech reception
13 threshold (SRT) was noted. The squelch test using white noise at 65 dB delivered to the deaf
14 side and monosyllabic words of increasing intensity presented frontally was performed in UA
15 condition and with Alpha 1[®], recording the SRT. Both tests aimed to measure the efficacy of
16 the system for the transfer of sound information to the contralateral side.

17 **Questionnaires**

18 Patient satisfaction with Alpha 1[®] was evaluated by Glasgow Benefit Inventory (GBI)
19 [Robinson et al., 1996] and by a specific questionnaire. The GBI was divided in 3 subgroups
20 (general, social support and physical health) and the results were reported from -100 to +100
21 for each subgroup and for the global score. The specific questionnaire investigated the
22 satisfaction of wearing the device through a Likert scale ranging from 0 to 4 (0= very
23 dissatisfied; 1= somewhat dissatisfied; 2 = neither satisfied nor dissatisfied; 3 = satisfied; 4 =
24 very satisfied).

1 Afterwards, the Alpha 2[®] external processor was delivered to all patients, and all the test and
2 questionnaires described above were repeated after 30 days with the Alpha 2[®] processor. The
3 same method of fitting was used across the patients and this fitting was normalized with air
4 conduction pure-tone average, as well as the same magnetic strength was maintained between
5 Alpha 1 and Alpha 2.

6 **Statistical analysis**

7 Values were expressed as means \pm SD. The results obtained with the two external processors
8 were analyzed by a paired t-test or by non-parametric Wilcoxon test because of the small
9 number of patients. Qualitative data were compared using Mc Nemar test. A p value < 0.05
10 was considered significant.

11

1 **RESULTS**

2 ~~All patients completed the protocol.~~

3 **Population**

4 There were 5 males and 4 females. The mean age was 50 ± 9.9 years (mean \pm SD, range
5 40/65 years); the right side was involved in 5 cases, the left side in 4 cases. The etiology of
6 unilateral hearing loss was vestibular schwannoma surgery (22%), sudden sensorineural
7 hearing loss (22%), chronic otitis (11.2%) with ipsilateral profound hearing loss, head trauma
8 (11.2%), ototoxicity (11.2%), mumps (11.2%), congenital (11.2%).

9 At the first visit with the Alpha 1[®], the local skin over the implant was evaluated normal in 8
10 cases and hyperemic in 1 case. The mean strength of the external magnet was 5 ± 1.7 N. The
11 mean wearing time per day was 5 ± 4.5 hours and the patients had a regular daily use of the
12 Alpha 1[®] in 5 cases, and an occasional use in 4 cases.

13 With the Alpha 2[®], the local skin was evaluated normal in 7 cases and hyperemic in 2 cases.
14 The strength of the external magnet was 5 ± 1.9 , and the wearing time was 7 ± 4.3 hours,
15 values that were similar to those obtained with Alpha 1[®]. One more patient used the Alpha 2[®]
16 regularly (6 instead of 5 for Alpha 1[®]).

17

18 **Audiological tests**

19 The mean air conduction threshold (mean of the frequencies 500, 1000, 2000 and 4000 Hz) of
20 the contralateral ear was 21 ± 9 dB and the bone conduction threshold was 14 ± 8.6 dB (Tab.
21 1).

22 The mean speech discrimination score (Fig. 2A) using monosyllabic words delivered at 40 dB
23 (73%) and at 60 dB (98%) was similar in UA condition and with Alpha 1[®]. Similarly, no
24 difference in SRT in both Hirsch's test (58dB) and squelch test (54 dB) was observed between
25 the UA condition and with the Alpha 1[®] (Fig. 2B).

1 At the 1 month audiological tests with Alpha 2[®], using monosyllabic words at 40 dB, the
2 speech discrimination score was $82 \pm 19.7\%$: the mean gain was $8 \pm 8\%$ and this difference
3 was significant (paired t-test; $p < 0.005$) (Fig. 2A).

4 At 60 dB, the speech discrimination score was $100 \pm 0.7\%$ with Alpha 2[®], a value not
5 different to that observed with Alpha 1[®].

6 Regarding the Hirsch's test (Fig. 2B), the SRT with Alpha 2[®] was similar to that observed
7 with Alpha 1[®] but it was improved by 4 ± 4 dB ($p < 0.02$, paired t-test) compared to UA condition.

8 For the squelch test, the SRT with Alpha 2[®] improved of 1.4 ± 1 dB ($p < 0.02$, paired t-test)
9 compared to that measured with Alpha 1[®].

10 **Questionnaires**

11 The GBI global score with Alpha 1[®] was 11 ± 12.9 , and the scores for the subscales were $12 \pm$
12 15.6 , 15 ± 22.7 and 6 ± 22.6 for the general, social support and physical health respectively;
13 Fig. 5). Patient's satisfaction stood at 2 ± 1.2 using the specific questionnaire.

14 Regarding the GBI score, with the use of Alpha 2[®] device we obtained a value of 14 ± 11.0
15 for the global score and 18 ± 18.3 , 18 ± 22.7 , -4 ± 11.1 for the general, social support and
16 physical health subscales respectively. There was no significance when comparing these data
17 to the results with the Alpha 1[®] processor (Fig. 3, Wilcoxon test).

18 The specific questionnaire revealed a score of 3 ± 0.3 with the Alpha 2[®] and the difference
19 with the score obtained with the Alpha 1[®] was not significant (Wilcoxon test).

20

21

1 **DISCUSSION**

2 The SSD certainly represents one of the most difficult clinical condition for hearing
3 rehabilitation: Studies analyzing the results of BAHA showed that the hearing outcomes and
4 the patient's satisfaction were significantly poorer in patients affected by SSD than in those
5 affected by conductive or mixed hearing loss [Tringali et al., 2008; Martin et al., 2010].
6 Furthermore, when using a trans-cutaneous bone conductive hearing device, the presence of
7 an intact skin, although beneficial from a clinical point of view, attenuates sound transmission
8 especially in high frequencies [Verstraeten et al., 2009; Kurz et al., 2014], and this could
9 decrease the efficiency of this device when used in SSD.

10 Sophono Alpha system is a bone conductive transcutaneous implant that transmits the
11 vibrations of the external processor through an intact skin, by means of a magnetic coupling.
12 It has been described firstly by Siegert et al. [Siegert, 2011] and since, other papers have been
13 published concerning the use of this device in different pathological conditions [Denoyelle et
14 al., 2013; Hol et al., 2013; Sylvester et al., 2013; Magliulo et al., 2014; Escorihuela-García et
15 al., 2014; Leterme et al., 2015; Siegert, and Kanderske, 2013].

16 The use of Alpha 1[®] system has already been described in conductive or mixed hearing loss in
17 adults and in children [Sylvester et al., 2013; Escorihuela-García et al., 2014; Siegert, and
18 Kanderske, 2013; Hol et al., 2013; Magliulo et al., 2014; Denoyelle et al., 2013]. No studies
19 have been yet published in the English literature with the use of Alpha 2[®].

20 After the release of the new external processor Alpha 2[®], we aimed to study if, regardless the
21 technological improvements of this new external processor, there were audiological
22 improvements with the use of this new device compared to the previous Alpha 1[®].

23 First of all, the new external processor is safe: no increase in adverse skin reactions was
24 observed and the patient's satisfaction improved, even if this was not significant in the
25 specific questionnaire and in the GBI due to the limited number of patients. Nevertheless the

1 results of the GBI questionnaires are similar to those obtained with the use of other bone
2 anchored hearing devices [Faber et al., 2013; Saroul et al., 2013] in SSD.
3 From an audiological point of view, as expected, the benefits of Alpha 2[®] are significant at 40
4 dB stimulation and this could be useful in improving speech perception of the deaf side. At 65
5 dB this difference is not significant probably because, at this level of stimulation, the normal
6 hearing ear is stimulated as well. Regarding hearing-in-noise tests, we observed a significant
7 differences for the squelch test: this test reflects the reduced masking of the speech by the
8 noise [Snik et al., 2015] and the improvement is probably due to the presence of the 2
9 microphones in the Alpha 2[®] external processor. For the Hirsch's test, even if there was an
10 improvement in the scores, this was not significant probably because of the low number of
11 cases. Anyway, if compared to unaided condition, the improvement with Alpha 2[®] was
12 significant.

13 In conclusion, the new external processor Alpha 2[®] improves the hearing performance in
14 patients with SSD compared to the previous Alpha 1[®] external processor; since this
15 pathological condition is one of the most challenging to rehabilitate, the upgrade revealed
16 beneficial for the patients.

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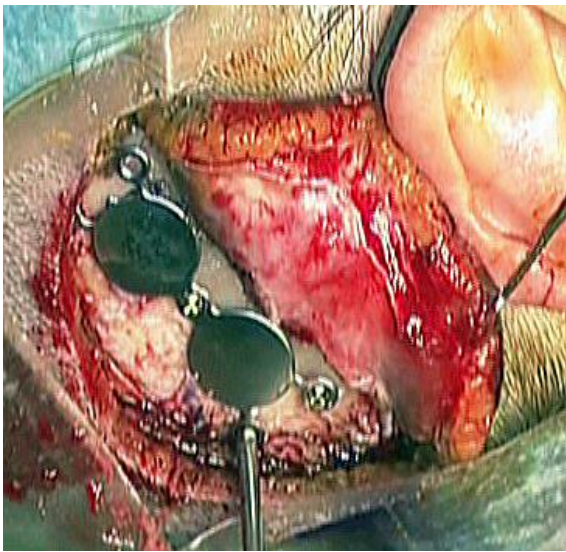
1 Fig. 1. A: Comparison between Alpha 1[®] (on the left) and Alpha 2[®] (on the right) external
2 processor . and after placement in the retroauricular region of the Alpha 2[®] (B). Surgical view
3 of internal magnet in place in a right ear (C)



4 A

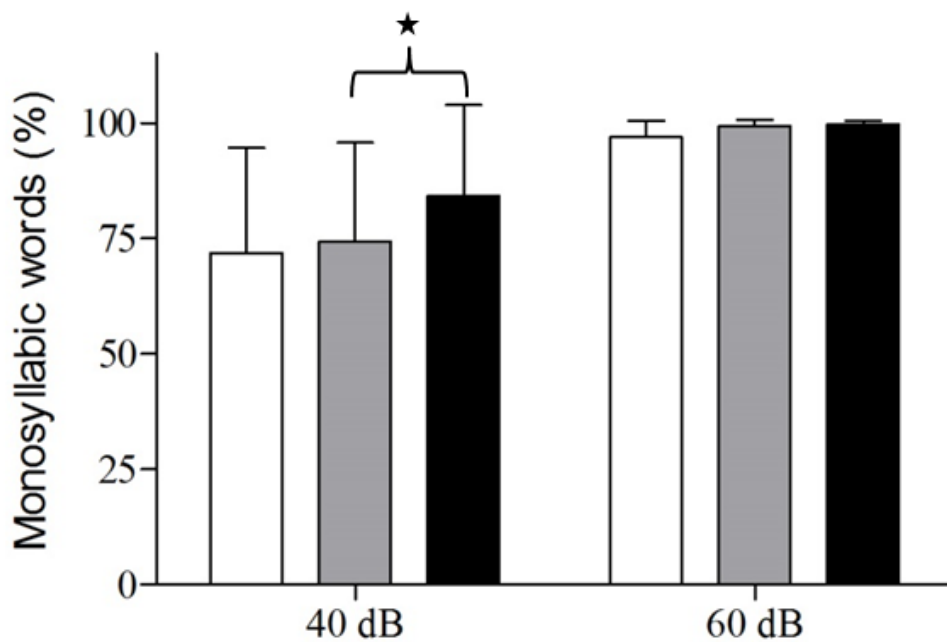


5 B



6 C

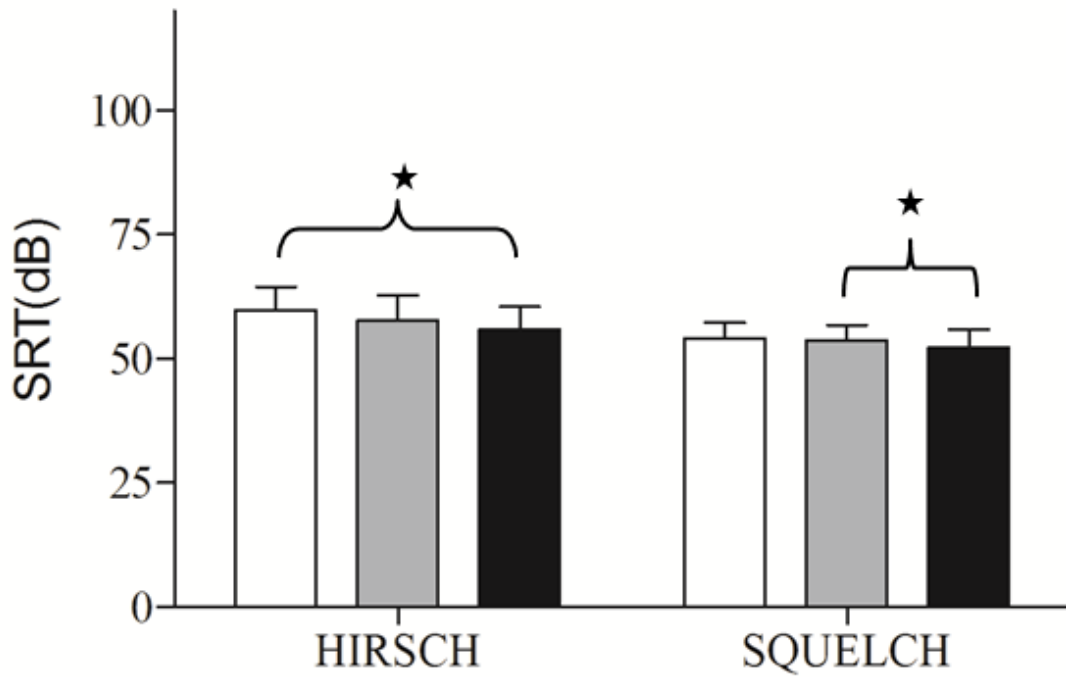
1 Fig. 2. (A) Free-field speech audiometry in quiet using monosyllabic words to the deaf side at
2 40 dB and 60 dB. The improvement of the speech discrimination score is significant with the
3 Alpha 2[®] compared to the Alpha 1[®] at 40 dB ($p=0.023$; paired t-test) white bars are test
4 performed in unaided condition, grey bars with Alpha 1[®] and black bars with Alpha 2[®]
5 external processor). (B) Speech discrimination in noise; Results of the Hirsch (left column)
6 and squelch tests (right column) in unaided (white bars), with Alpha 1[®] (gray bars) and with
7 Alpha 2[®] (black bars). For the Hirsch test, the improvement between unaided condition and
8 Alpha 2 is significant ($p<0.02$, paired t-test). For the squelch test, the improvement in the
9 speech reception threshold (SRT) is significant ($p=0.016$; paired t-test) .



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A

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1

B

2 Fig. 4. Results of the Hirsch (left column) and squelch tests (right column) in unaided (white
 3 bars), with Alpha 1[®] (gray bars) and with Alpha 2[®] (black bars). For the squelch test, the
 4 difference between the 2 test is significant (p=0.016; SRT: speech reception threshold)

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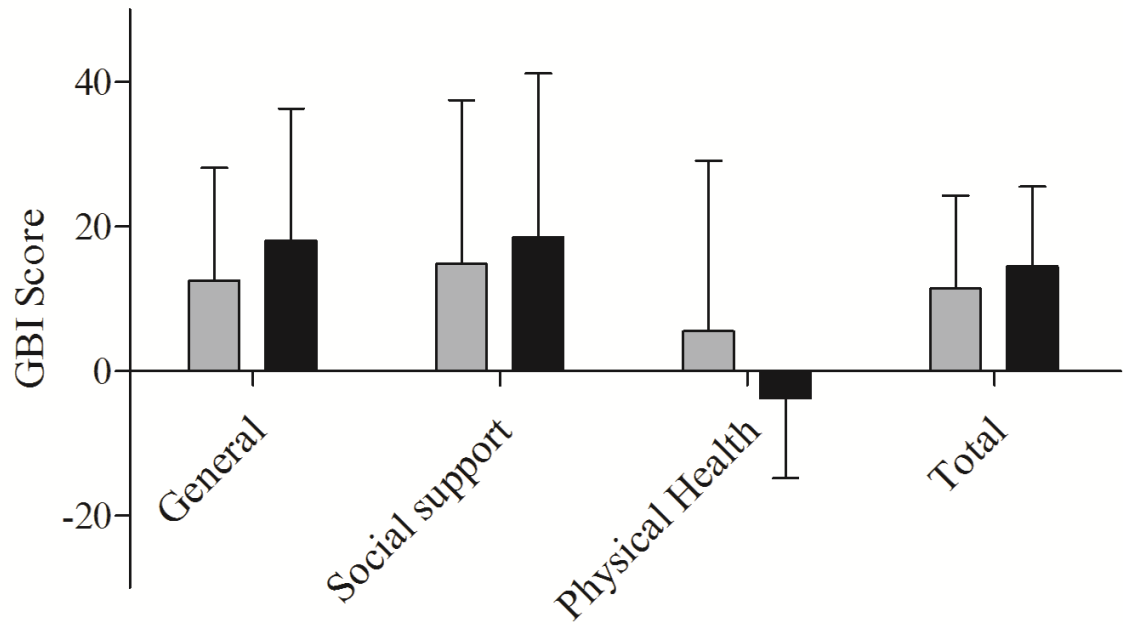
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- 1 Fig. 3. Glasgow Benefit Inventory (GBI) questionnaire showed no statistically significant
- 2 differences between the 2 devices (Wilcoxon non parametric test). Grey bars: with Alpha 1[®];
- 3 black bars: with Alpha 2[®].



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