SHORT REPORT

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BAHA® implantation in pediatric patients: indications and clinical outcomes

Ugradnja aparata BAHA® bolesnicima dečjeg uzrasta: indikacije i rezultati

Ivan Baljošević*†, Ljiljana Čvorović‡§, Maša Petrović‡‖, Svetozar Memarović§

***Institute for Mother and Child Health Care of Serbia "Dr. Vukan Čupić", Department of Pediatric Otorhinolaryngology, Belgrade, Serbia; †University of Business Academy, Faculty of Dentistry, Pančevo, Serbia; ‡University of Belgrade, Faculty of Medicine, Belgrade, Serbia; §University Clinical Center of Serbia, Clinic for Otorhinolaryngology and Maxillofacial Surgery, Belgrade, Serbia; ‖Institute for Cardiovascular Diseases "Dedinje", Belgrade, Serbia**

Abstract

Background/Aim. Bone-anchored hearing aids (BAHA®) are implantable devices that transmit sound through bone conduction directly to the inner ear. They are indicated for patients with conductive or mixed hearing loss who cannot benefit from conventional hearing aids. The aim of this study was to evaluate surgical outcomes, postoperative complications, and audiological improvements following percutaneous and transcutaneous BAHA® implantation in a pediatric cohort. **Methods.** A retrospective cohort study was carried out on 20 children who underwent BAHA® implantation between 2011 and 2024. Demographic data, clinical indications, syndromic associations, audiological findings, and postoperative complications were analyzed. Statistical analyses included Fisher's exact test and the Wilcoxon signed-rank test, with significance set at $p < 0.05$. **Results.** Out of the total of 20 patients (60% male; mean age 6.3 years), 11 received percutaneous and 9 transcutaneous BAHA® devices. The primary indications were congenital anomalies (50%), notably Treacher-Collins syndrome and isolated atresia. In patients with a percutaneous BAHA® device, skin infections were recorded in 3 (27%) of 11 patients, and they were accompanied by skin overgrowth, which required revision surgery in 2 (18%) patients. In the group implanted with the transcutaneous BAHA® Attract device, paresthesia and skin erythema were observed in one case each. The mean hearing improvement was 36.6 dB with percutaneous BAHA® devices and 31.7 dB with BAHA® Attract devices at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz. Significant postoperative hearing improvement was achieved in all patients ($p = 0.0002$). **Conclusion.** BAHA® implantation provides significant hearing rehabilitation in children with conductive or mixed hearing loss. The transcutaneous system demonstrates comparable audiological outcomes with fewer complications and superior cosmetic acceptability compared to the percutaneous system.

Keywords:
child; child, preschool; hearing aids; hearing loss, conductive; hearing loss, sensorineural; otorhinolaryngologic surgical procedures; treatment outcome.

Apstrakt

Uvod/Cilj. *Bone-anchored hearing aids* (BAHA®) su implantabilna pomagala kojima se, putem koštane provodljivosti, zvuk prenosi direktno u unutrašnje uvo. Indikovani su za obolele od konduktivnog ili mešovitog gubitka sluha, koji ne mogu imati koristi od konvencionalnih slušnih pomagala. Cilj rada bio je da se procene hirurški ishodi, postoperativne komplikacije i audiološka poboljšanja posle perkutane i transkutane implantacije BAHA® u pedijatrijskoj kohorti. **Metode.** Retrospektivna kohortna studija sprovedena je na 20-oro dece, kojima je izvršena ugradnja uređaja BAHA® između 2011. i 2024. godine. Analizirani su demografski podaci, kliničke indikacije, udruženost sa sindromima, audiološki nalazi i postoperativne komplikacije. Statistička analiza uključila je Fisher-ov egzaktni test i Wilcoxon-ov test uparenih rangova, pri čemu je nivo statističke značajnosti postavljen na $p < 0,05$. **Rezultati.** Od ukupno 20 bolesnika (60% muškog pola; prosečanog uzrasta 6,3 godine), kod 11 je ugrađen perkutani, a kod 9 transkutani aparat BAHA®. Primarne indikacije bile su kongenitalne anomalije (50%), naročito Treacher-Collins-ov sindrom i izolovana atrezija. Kod bolesnika sa perkutanim BAHA® aparatom registrovane su infekcije kože kod 3 (27%) od 11 bolesnika i bile su praćene hipertrofijom kože koje su zahtevale reintervenciju kod dvoje (18%) dece. U grupi kod

Correspondence to: Ivan Baljošević, Mother and Child Health Institute of Serbia "Dr. Vukan Čupić", Department of Otorhinolaryngology, Radoja Dakića 6, 11 070 Belgrade, Serbia. E-mail: ivan.baljosevic@gmail.com

koje je bio implantiran transkutani BAHA® Attract aparat zabeleženi su parestezija i eritem kože u po jednom slučaju. Prosečno poboljšanje sluha bilo je 36,6 dB sa perkutanim aparatom BAHA®, a 31,7 dB sa aparatom BAHA® Attract na 0.5 kHz, 1 kHz, 2 kHz i 4 kHz. Kod svih bolesnika postignuto je značajno postoperativno poboljšanje sluha ($p = 0{,}0002$). **Zaključak.** Ugradnja aparata BAHA® obezbeđuje značajnu rehabilitaciju sluha kod dece obolele od konduktivnog ili mešovitog oštećenja sluha. Transkutani sistem pokazuje uporedive audiološke ishode uz manje komplikacija i bolju estetsku prihvatljivost u poređenju sa perkutanim sistemom.

Ključne reči:
deca; deca, predškolska; sluh, pomagala; sluh, konduktivni gubitak; sluh, senzornonervni gubitak; hirurgija, otorinolaringološka, procedure; lečenje, ishod.

Introduction

Bone-anchored hearing aids (BAHA®) are specialized hearing devices developed to facilitate sound conduction through bone. This technology, initially introduced in Gothenburg, Sweden, in 1977, uses titanium implants that integrate with bone and are surgically placed behind the ear. BAHA® devices were designed primarily to assist patients with conductive and mixed types of hearing loss by transmitting sound vibrations directly through the bone to the inner ear, bypassing the outer and middle ears [1, 2]. Today, more than 150,000 individuals with hearing impairments use BAHA® devices. These devices are particularly beneficial for patients who are unable to achieve satisfactory hearing improvement with conventional hearing aids, including those with unilateral deafness or conductive/mixed hearing loss.

Two main types of bone conduction implants are now available: percutaneous (transdermal) and transcutaneous (non-penetrating). The percutaneous BAHA® device includes a titanium implant connected to an abutment and sound processor, allowing for direct sound transmission. However, ongoing maintenance and meticulous hygiene are required to prevent complications. The transcutaneous BAHA® Attract system, introduced in 2013, consists of a titanium implant and two magnets: one subcutaneous, connected to the implant, and one external magnet connected to the sound processor. A soft material pad distributes pressure evenly across the skin, improving comfort and reducing the risk of irritation [3]. In cases of insufficient bone thickness, a new opening is created in the bone to allow secure placement of the titanium implant.

This study aimed to assess the surgical outcomes of percutaneous and transcutaneous BAHA® implants, evaluate postoperative complications, and measure improvements in hearing thresholds in pediatric patients who underwent BAHA® implantation at a tertiary care center.

Methods

This retrospective cohort study was conducted at the Institute for Mother and Child Health Care of Serbia "Dr. Vukan Čupić", a tertiary care institution in Belgrade, Serbia. Between 2011 and 2024, BAHA® implants were placed in 20 pediatric patients with conductive or mixed hearing loss. This study was approved by the Ethics Committee of the Institute (Approval No. 8/135, from March 27, 2024).

The study included patients with severe conductive hearing loss due to congenital anomalies or those who had previously undergone surgery for chronic suppurative otitis media with cholesteatoma. Patients with acute unilateral deafness were also included. All of these patients were unable to use conventional hearing aids for auditory rehabilitation due to ear deformities, repeated surgical interventions, or complete deafness. Due to financial constraints, no surgeries were performed from 2012 to 2014, and because of the COVID-19 pandemic, surgical procedures were paused between March 2020 and March 2022. Therefore, this study spans an effective period of 9 years.

The percutaneous BAHA® system was the only available type for implantation and was used until 2017 (Figures 1 and 2). Implantation of the transcutaneous BAHA® Attract system commenced in 2017 (Figures 3 and 4). The

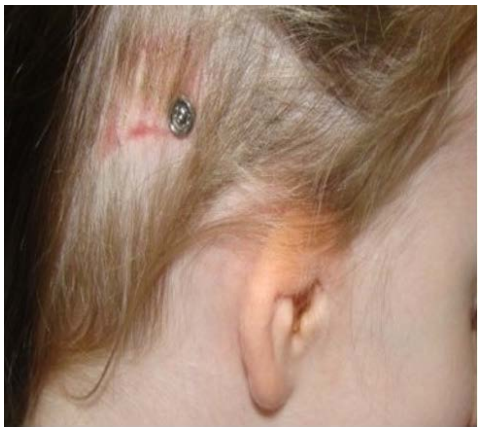

Fig. 1 – Percutaneous BAHA® implant – a titanium implant inserted into the cranial bone *via* a skin incision, with an abutment affixed to it. BAHA – bone-anchored hearing aid.

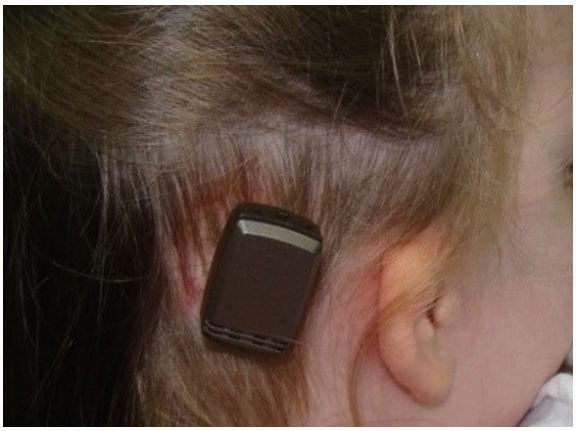

Fig. 2 – BAHA® sound processor attached to the percutaneous abutment. BAHA – bone-anchored hearing aid.

parents were fully informed about the treatment options, risks, and benefits of the procedure, and written consent was obtained prior to surgery.

The baseline data collected included patient demographics, clinical presentation, audiological findings, and any relevant syndromic associations. Preoperative pure-tone audiograms were obtained. In pure-tone audiometry, the hearing threshold for air conduction was calculated as the mean of the thresholds measured at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz. This threshold was measured in decibels (dB) hearing level (HL). All patients wore a soft-band BAHA® for a period of at least 1 to 6 months before surgery. Patients with conductive hearing loss received BP110 processors, while those with sensorineural hearing loss received BP110P processors. Following the introduction of the BAHA® Attract system (after 2017), the BAHA® 5 Power and BAHA® 6 Max processors were used; these devices were more compact and enabled synchronization with a mobile phone application. Comprehensive pediatric evaluations were conducted to identify other congenital anomalies or syndromic associations. Cochlear™ BAHA® devices (Cochlear, Sweden) were used in all cases.

Surgical procedures for both percutaneous and transcutaneous BAHA® devices followed the manufacturer's guidelines.

Descriptive and analytical statistics were computed using IBM SPSS v21. Descriptive statistics included absolute and relative frequencies (numbers and percentages), measures of central tendency (means), and dispersion (ranges). Analytical tests included Fisher's exact test and the Wilcoxon signed-rank test, with statistical significance set at $p < 0.05$.

Results

General characteristics

The average age of patients was 6.3 years (range 4.5–15 years), with a predominance of males (60%).

The most common indications for implantation included congenital anomalies of the outer and middle ear (50%), consisting of Treacher-Collins syndrome (5 patients), isolated atresia (4 patients), and Crouzon syndrome (1 patient). Other indications were chronic middle ear cholesteatoma (6 patients - 30%), and unilateral deafness in 4 (20%) children (Table 1).

Hearing aid implantation stages

The implantation sites were marked preoperatively, positioning the processor approximately 5–7 cm behind the ear canal at the level of the temporal line. Among 20 patients, 11 (55%) received a percutaneous BAHA® device, while 9 (45%) received a BAHA® Attract device.

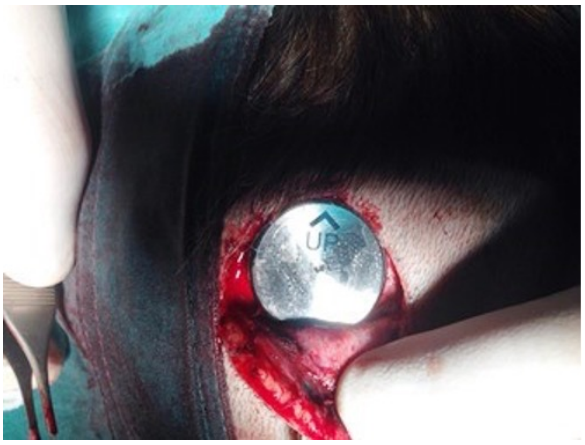

Fig. 3 – BAHA® Attract – magnetic plate positioned on the titanium implant with the "UP" mark facing upward. BAHA – bone-anchored hearing aids.

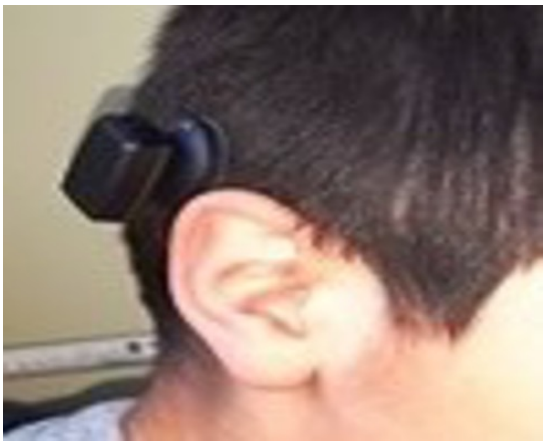

Fig. 4 – BAHA® Attract processor placed over intact skin and hair, directly above the subcutaneous magnetic plate. BAHA – bone-anchored hearing aids.

Table 1

Overview of indications for patients with BAHA® implants

Indication	Percutaneous	Transcutaneous	Total
Congenital anomalies of the outer and middle ear			10 (50)
isolated atresia	1 (25)	3 (75)	4 (20)
Treacher-Collins syndrome	4 (80)	1 (20)	5 (25)
Crouzon syndrome	0 (0)	1 (100)	1 (5)
Chronic suppurative otitis media with cholesteatoma	5 (83.3)	1 (16.7)	6 (30)
Unilateral total deafness	1 (25)	3 (75)	4 (20)

BAHA – bone-anchored hearing aids.
All values are presented as numbers (percentages).
***Note:* Rarer indications are also given as numbers (percentages), but in relation to the three most common indications.**

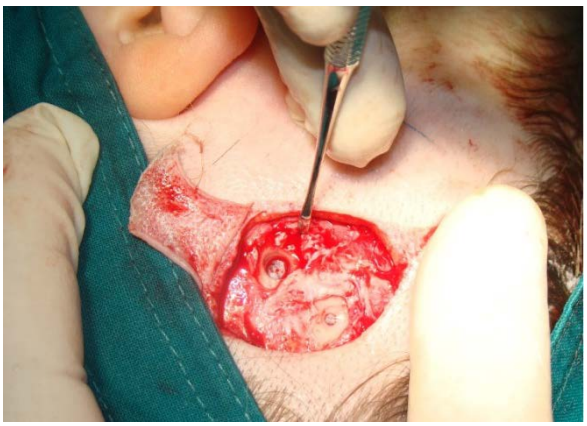

Fig. 5 – New opening created in the direction of the instrument due to insufficient cranial bone thickness to accommodate the titanium implant.

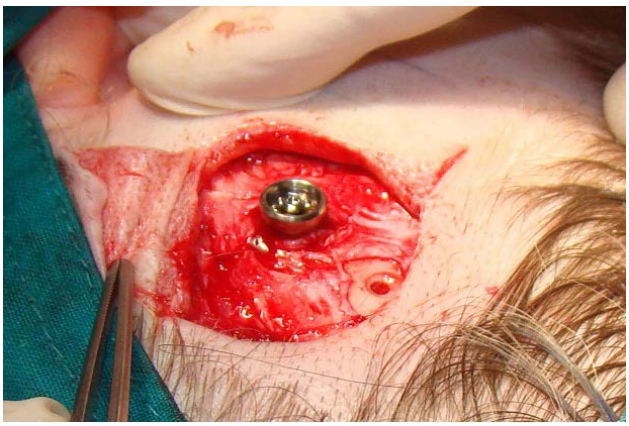

Fig. 6 – Titanium implant and abutment positioned in the newly created, adequately deep opening in the cranial bone.

Soft tissue thickness was less than 6 mm in all cases, allowing for implant placement without soft tissue reduction. A 4-mm implant was used in each case.

During surgery, 14 (70%) patients experienced no complications. In 2 (10%) patients, significant bleeding from the bone was observed, and in 4 (20%) patients, insufficient bone thickness necessitated creating a new opening to ensure stable implant placement (Figures 5 and 6). In one patient, three attempts were required before an adequate bone-thickness site was identified.

The average operative time for percutaneous and transcutaneous BAHA® implantation was similar, ranging from 40 to 47 min, with a mean of 42 min.

Outcomes

Wound healing was uneventful in all cases. The sound processor was connected one month postoperatively.

Preoperative hearing thresholds were calculated as the average of the thresholds measured at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz. These baseline pure-tone averages were 40–60 dB HL in 4 patients and 60–80 dB HL in 12 patients. The remaining 4 patients presented with complete deafness. Postoperatively, hearing thresholds improved in all patients, reaching 20–40 dB HL across the cohort. The mean hearing improvement was 36.6 dB for percutaneous devices and 31.7 dB for BAHA® Attract at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz, with an average final threshold of 27 dB. A statistically significant improvement in hearing thresholds was observed postoperatively for both device types ($p = 0.0002$).

In patients with a percutaneous BAHA® device, skin infections were recorded in 3 (27%) out of 11 patients, accompanied by skin overgrowth, which required revision surgery in 2 (18%) patients. In the BAHA® Attract group, paresthesia occurred in one patient and erythema occurred in another; adjustment of the magnet strength resolved these symptoms.

There was no significant difference in complication rates between the percutaneous and transcutaneous BAHA® devices ($p = 0.635$). Although the percutaneous group showed slightly more complications, the difference was not statistically significant. Given the small sample size, the study may be underpowered to detect minor differences in complication rates.

Discussion

The BAHA® device functions by bypassing the hearing mechanism of the outer and middle ear, transmitting sound directly to the cochlea through the cranial bone. Consequently, it is particularly suitable for patients with outer ear deformities, such as microtia and anotia. Patients with chronic suppurative otitis media, adhesive otitis media, external otitis, or frequent outer ear infections who cannot use conventional hearing aids also benefit greatly from BAHA® use [4].

In our study, the most common indication for intervention was congenital anomalies of the outer and middle ear, accounting for 10 (50%) patients, most often presenting as part of various syndromes. Due to these anatomical variations, these patients were unable to use conventional hearing amplifiers, making BAHA® implantation the only viable solution. Additionally, children who have undergone surgery for middle ear cholesteatoma may still experience occasional purulent ear infections, hindering the use of standard hearing aids. Our study included 6 (30%) of such patients.

The indications should have been expanded to include patients with conductive hearing loss, mixed hearing loss, or single-sided deafness. In such cases, sound is transmitted transcranially to the other healthy ear, providing patients with stereo hearing. In our study, 4 (20%) patients fell into the category of unilateral total deafness. The use of BAHA® improves audibility and sound quality, thereby enhancing the overall quality of life for these patients.

Percutaneous BAHA® devices facilitate direct sound transmission but present challenges, including aesthetic concerns and the risk of skin complications at the implant site. In contrast, BAHA® Attract devices offer a transcutaneous solution that minimizes skin complications by shielding the implant from direct contact. This approach eliminates the need for daily skin care at the implant site and provides superior aesthetic outcomes [5, 6].

In our study, the average operative time for percutaneous and transcutaneous BAHA® implantations was similar, ranging from 40 to 47 min, with a mean of 42 min. This aligns with previously reported times in the literature, which range from 37 min to 57 min [7, 8]. During BAHA® Attract implantation, soft tissue reduction may be required, occurring in 11.1% to 31.2% of cases [8, 9], depending on individual variations in skin and subcutaneous tissue thickness. In our cohort, soft tissue reduction was not necessary.

Gawecki et al. [3] reported intraoperative complications in 12.1% of 125 patients receiving BAHA® implants, including bleeding, abnormal bone morphology, and insufficient bone thickness. Hougaard et al. [7] described the use of 3-mm implants in cases where the dura was exposed after drilling to a depth of 3 mm. Major postoperative complications were rare, and healing was uncomplicated in most cases. Minor hematomas were noted in 7.2% of patients on the day following surgery [3]. In our study, intraoperative complications included significant bleeding in 2 patients, which was successfully controlled with wax tamponade. In addition, insufficient bone thickness in 4 children necessitated the creation of a new opening for implant placement.

It is generally accepted that hearing gain with the BAHA® Attract system is lower than with percutaneous BAHA®. Audiometric measurements are performed at 4 and 6 weeks and at 3 and 6 months postoperatively. A gradual improvement in hearing performance up to 3 months, as described by Briggs et al. [10], is established but not statistically significant between the two types of implants. The improvement in hearing performance, particularly between 4 and 6 weeks, is attributed to gradual patient adaptation, progressively improved magnet-to-bone contact, and fine-tuning by the audiologist, with sound amplification gradually increased. After 3 months, a relative stabilization of audiometric threshold levels occurs [11]. Vaughan-Christensen et al. [12] also stated that patients are satisfied with the sound provided by the BAHA® Attract system. They noted that in more recent comparisons, they found no statistically significant group differences between the percutaneous and transcutaneous systems. Iseri et al. [8] also reported similar audiometric thresholds at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz in adults between the percutaneous and transcutaneous systems.

In our study, the mean hearing improvement was 36.6 dB with percutaneous BAHA® devices and 31.7 dB with BAHA® Attract devices at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz, with an average aided hearing threshold of 27 dB. Studies by Baker et al. [13] and Powell et al. [14] predominantly investigated pediatric populations, reporting greater improvements in mean aided thresholds (41 dB HL and 30.6 dB HL, respectively) compared with studies involving predominantly adult populations, such as that by Briggs et al. [10], who reported an improvement of 18.4 dB HL. Late complications, defined as those occurring 7 or more days after surgery, are described in the literature. These complications are more frequent and more severe in patients with percutaneous BAHA® devices. In these patients, daily cleaning and maintenance of the skin-penetrating implant site are required, which may lead to skin infections accompanied by excessive skin overgrowth. Thus, poor and irregular hygiene of the skin around the abutment leads to skin hypertrophy, which can even completely cover the implant. In our study, skin infections occurred in 27% of patients with percutaneous implants; skin infection rates reported in the literature range from 8% to 59%. Skin hypertrophy can result in skin overgrowth covering the implant, necessitating revision surgery in 5–42% of cases [15–18]; in our cohort, revision surgery was required in 18% of patients.

In contrast, complications following BAHA® Attract implantation are significantly milder and less frequent. Seroma or hematoma formation has been reported in 4.4% of cases and was managed conservatively [8], while 8.9% of patients experienced numbness around the flap area [9]. In our pediatric cohort with BAHA® Attract system implantation, paresthesia and skin erythema were observed in one case each. In both instances, a reduction of the magnet strength resulted in clinical improvement.

Conclusion

BAHA® implantation has proven to be an effective method of auditory rehabilitation in children with conductive or mixed hearing loss who are unresponsive to conventional hearing aids. This procedure enhances a child's spatial orientation, speech development, and intellectual growth. The BAHA® Attract system, in particular, offers a safe and minimally invasive alternative with rapid healing, excellent aesthetic outcomes, and a reduced risk of complications.

Conflicts of interest

The authors of this paper certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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