Electric-acoustic stimulation suppresses tinnitus in a subject with high-frequency single-sided deafness

Electric-Acoustic Stimulation Suppresses Tinnitus in a Subject with High-frequency Single-sided Deafness

Griet Mertens[1,2], Vincent Van Rompaey[1,2], Paul Van de Heyning[1,2]

[1]*Univ. Dept. Otorhinolaryngology and Head and Neck Surgery, Antwerp University Hospital, Edegem, Belgium*

[2]*Faculty of Medicine and Health Sciences, University of Antwerp, Belgium*

Corresponding Author

Griet Mertens

Antwerp University Hospital,

Department of Otolaryngology and Head and Neck Surgery,

Wilrijkstraat 10,

2650 Edegem,

Belgium.

Tel: 0032-38214059

Fax: 0032-38250536

Conflicts of Interest and Source of Funding

The Antwerp University Hospital is currently receiving a grant from MED-EL and the University of Antwerp a TOPBOF (Bijzonder Onderzoeksfonds) grant.

Key words

Partial deafness, tinnitus suppression, electric acoustic stimulation

ABSTRACT

Background: A suggested solution to suppressing tinnitus is to restore the normal sensory input. This is based on the auditory deprivation hypothesis. It is known that hearing aids can provide sufficient activation of the auditory nervous system and reduce tinnitus in subjects with mild to moderate hearing loss and that cochlear implantation can reduce tinnitus in subjects with severe to profound hearing loss. This applies to subjects with single-sided deafness (SSD) or bilateral hearing loss.

Aim: To investigate if electric acoustic stimulation (EAS) can reduce severe tinnitus in a subject with residual hearing in the ipsilateral ear and contralateral normal hearing (high-frequency SSD) by restoring the auditory input.

Methods: Tinnitus reduction was investigated for 1 year after implantation in a subject with high-frequency SSD, using EAS, and was compared to 11 subjects with a cochlear implant with SSD. The visual analogue scale (VAS) and the tinnitus questionnaire (TQ) were administered preoperatively and at 1-, 3-, 6- and 12-months after implantation.

Results: Significant tinnitus reduction was observed 1 month after implantation on the VAS in the subjects with SSD using a cochlear implant. Tinnitus reduction was also observed in the subject with high-frequency SSD using EAS. A further decrease was observed 3 months after implantation. The TQ and VAS scores remained stable up to 1 year after implantation.

Conclusion: A cochlear implant can significantly reduce ipsilateral severe tinnitus in a subject with SSD. Ipsilateral severe tinnitus can also be reduced using EAS in subjects with high-frequency SSD.

INTRODUCTION

Tinnitus, an auditory phantom sensation experienced in the absence of an external physical sound source, is reported to occur in up to 30% of individuals in developed countries. 10 to 15% of the individuals experience symptoms that are significant enough to require medical attention (Heller 2003, Van de Heyning et al. 2015).

Tinnitus can generally be classified into two categories: objective and subjective tinnitus. Objective tinnitus accounts for less than 5% of overall tinnitus cases and often arises from an internal physical source (e.g. vascular or muscular disorders). In many instances, the cause of objective tinnitus can be determined and treatment - either medical or surgical - may be prescribed. The underlying pathophysiology of subjective tinnitus, on the other hand, remains unclear. One of the hypotheses is that tinnitus arises from changes in neural activity caused by a reduced (or lost) auditory input. Although the pathophysiologic mechanism underlying tinnitus still remains unclear, it has been shown that tinnitus is highly associated with hearing loss (85% of the tinnitus cases) (Arts et al. 2012).

A solution that is suggested to suppress tinnitus, based on the auditory deprivation hypothesis, is the restoration of normal sensory input. Del Bo and Ambrosetti (2007), for example, stated that hearing aids can provide sufficient activation of the auditory nervous system to reduce tinnitus in subjects with mild to moderate hearing loss. However, hearing aids cannot provide sufficient amplification in subjects with severe to profound hearing loss that suffer from tinnitus. Van de Heyning et al. (2008) reported the first study in which cochlear implantation was used to treat unilateral tinnitus in single-sided deafness (SSD). For the success of the treatment, the authors emphasized the importance of the inclusion criteria used (i.e. subjects must suffer from unilateral severe, intractable tinnitus, resulting from ipsilateral sensorineural hearing loss). Successive studies have confirmed these findings showing that cochlear implantation is a valuable treatment of severe tinnitus in subjects with SSD. Long-term results

show that cochlear implantation provides durable tinnitus relief in patients (Van de Heyning, Vermeire et al. 2008, Kleinjung et al. 2009, Buechner et al. 2010, Masgoret Palau et al. 2010, Arndt et al. 2011, Mertens 2015).

However, there are no studies that report on tinnitus reduction in subjects with residual hearing in the ipsilateral ear and contralateral normal hearing (high-frequency SSD) by restoring the normal sensory auditory input. Residual hearing is characterized by normal or slightly elevated hearing thresholds in the low frequencies and almost complete hearing loss in the higher frequencies. The hearing of subjects with high-frequency SSD is not poor enough to be treated with a cochlear implant (CI). A hearing aid, on the other hand, may not provide sufficient auditory activation to reduce the ipsilateral tinnitus in subjects with high-frequency SSD. To restore the high-frequency signals in these subjects, Von Ilberg et al. (1999) introduced the well-known electric acoustic stimulation (EAS) system. The EAS system combines electrical stimulation for high-frequency sounds, with preserved acoustic hearing for low-frequency information.

The present study is a case study on the influence of EAS on ipsilateral severe tinnitus in a subject with high-frequency SSD. This subject is hereinafter referred to as the EAS-SSD subject. The case study observations are compared to an SSD group with ipsilateral severe tinnitus using a CI (hereinafter referred to as CI-SSD subjects).

METHODS

Subjects

EAS-SSD Subject

The EAS-SSD subject is a female subject with residual hearing, with accompanied ipsilateral incapacitating tinnitus after sudden deafness, and contralateral normal hearing (i.e. $PTA_{0.5,\ 1,\ 2\ and\ 4\ kHz} \leq 30$ dB HL). She was implanted with a CI in her left ear at the age of 46 years. The pure tone average ($PTA_{0.5,\ 1,\ 2\ and\ 4\ kHz}$) of her contralateral normal hearing ear is 10 dB HL.

CI-SSD Subjects

A comparison was made between the EAS-SSD subject and 11 subjects suffering from SSD (i.e. air conduction pure tone average ($PTA_{0.5,\ 1,\ 2\ and\ 4\ kHz}$) in the profound unilateral sensorineural deaf ear ≥ 85 dB HL) and accompanying ipsilateral incapacitating tinnitus (Pre-operative Tinnitus Loudness Visual Analogue Scale (VAS) score >6/10) and contralateral normal hearing (i.e. $PTA_{0.5,\ 1,\ 2\ and\ 4\ kHz} \leq 30$ dB HL). They were implanted with a CI at a median age of 55 years (22-71 years) (Table 1). The complete inclusion criteria can be found in Van de Heyning et al. (2008).

Methods

Test Set-up

Tinnitus reduction in an EAS-SSD subject and in a comparative group of 11 CI-SSD subjects was studied up to one year post-implantation. The visual analogue scale (VAS and the tinnitus questionnaire (TQ) were administered preoperatively and at 1 month, 3 months, 6 months and 12 months after implantation. Descriptive statistics were applied to report demographic characteristics. Given the relatively small sample size, quantitative data are presented as median and range (minimum and maximum), and nonparametric statistics were used. Wilcoxon signed-rank tests were used to examine differences between data at the different

test intervals. Statistical analysis tests include two-tailed tests. Local ethics committee approval was obtained. All subjects gave written informed consent prior to participation in this study.

Tests

Unaided Hearing Thresholds

Unaided audiometric thresholds were obtained bilaterally using insert earphones (5A10). Audiometry was performed in a sound-isolated room, using an Interacoustics AC40 Clinical audiometer.

Visual Analogue Scale

A VAS was used to assess subjective tinnitus loudness pre-operatively, and at 1-, 3-, 6- and 12-months post-operatively. This is a simple 'analogue' line, 10 cm in length, anchored by 0 = “Quiet” and 10 = “Very loud, cannot get any worse”'. The subject marks on the continuous line the point that represents their perception of tinnitus loudness. The VAS score is determined by measuring in millimetres from the left hand end of the line to the marked point (Wewers and Lowe 1990).

Tinnitus Questionnaire

The TQ was used to quantify tinnitus pre-operatively, and at 1-, 3-, 6- and 12-months post-operatively. This widely used questionnaire was developed by Hallam et al. (Hallam et al. 1988) and modified by Goebel and Hiller (Hiller and Goebel 1992). The questionnaire is recommended as an outcome measure in clinical trials in a consensus document of the Tinnitus Research Initiative (TRI) (Langguth et al. 2007).

RESULTS

Unaided Hearing Thresholds

Pre-operative bilateral unaided audiometric thresholds are shown in Fig. 1. The EAS-SSD subject and the CI-SSD subjects all had normal hearing in their non-implanted ear (i.e. $PTA_{0.5,\ 1,\ 2\ and\ 4\ kHz} \leq 30$ dB HL). In the implanted ear, the EAS-SSD subject had high-frequency hearing loss (residual hearing) and the CI-SSD subjects had profound unilateral sensorineural hearing loss (i.e. $PTA_{0.5,\ 1,\ 2\ and\ 4\ kHz} \geq 85$ dB HL).

Visual Analogue Scale

The median pre-operative $VAS_{loudness}$ score of the CI-SSD subjects and of the EAS-SSD subject was 8 (range 8-10). Between preoperative measurement and 1 month after implantation, tinnitus loudness scores measured with the VAS significantly decreased to 5 (range 0-10) in the CI-SSD subjects ($p<0.01$) and to 6 in the EAS-SSD subject. Tinnitus loudness scores significantly decreased to 3.5 (range 0-7) in the CI-SSD subjects and to 3 in the EAS-SSD subject between 1 month and 3 months after implantation ($p<0.01$). No significant changes were observed between 3 and 12 months after implantation in the CI-SSD subjects.

Tinnitus Questionnaire

The median pre-operative TQ score was 56.5 (range 27-78) in the CI-SSD subjects and 54 in the EAS-SSD subject. Between preoperative measurement and 1 month after implantation, the TQ score significantly decreased to 45 (range 12-64) in the CI-SSD subjects ($p< 0.05$) and

to 43 in the EAS-SSD subject. TQ scores significantly decreased to 29 (range 9-59) in the CI-SSD subjects and increased to 51 in the EAS-SSD subject between 1 month and 3 months after implantation ($p<0.05$). No significant changes were observed between 3 and 12 months after implantation in the CI-SSD subjects (Fig. 3).

DISCUSSION

The present study confirms the outcomes of the publicly available studies that cochlear implantation is a valuable treatment option in SSD. This result is comparable with that of studies investigating tinnitus suppression after cochlear implantation in bilateral deafness (Arts, George et al. 2012). The present study showed the same trend with an EAS system in a high-frequency SSD subject. Still, the underlying mechanism of tinnitus reduction remains unclear in the EAS-SSD subject and in the CI-SSD subjects. Afferent information in the auditory nerve increases with EAS or CI, which may reduce tinnitus as it possibly reverses the responsible neural changes. However, the improved hearing after implantation may also result in less direct awareness of the tinnitus (Arts, George et al. 2012). Studies by Zeng et al. (2011) and Arts et al. (2015) support the hypothesis that afferent information in the auditory nerve increases, to reduce tinnitus. They reported that tinnitus decreased after intra-cochlear electrical stimulation, independent of environmental sounds generated by the CI in SSD subjects. However, more research is needed to gain insight into the underlying mechanism of tinnitus reduction in SSD subjects with an EAS or CI.

ACKNOWLEDGEMENTS

The authors thank the subjects who graciously gave their time and effort to participate.

REFERENCES

Arndt, S., A. Aschendorff, R. Laszig, et al. (2011). "Comparison of pseudobinaural hearing to real binaural hearing rehabilitation after cochlear implantation in patients with unilateral deafness and tinnitus." Otol Neurotol 32(1): 39-47.

Arts, R. A., E. L. George, A. Griessner, et al. (2015). "Tinnitus Suppression by Intracochlear Electrical Stimulation in Single-Sided Deafness: A Prospective Clinical Trial - Part I." Audiol Neurootol 20(5): 294-313.

Arts, R. A., E. L. George, R. J. Stokroos, et al. (2012). "Review: cochlear implants as a treatment of tinnitus in single-sided deafness." Curr Opin Otolaryngol Head Neck Surg 20(5): 398-403.

Buechner, A., M. Brendel, A. Lesinski-Schiedat, et al. (2010). "Cochlear implantation in unilateral deaf subjects associated with ipsilateral tinnitus." Otol Neurotol 31(9): 1381-1385.

Del Bo, L. and U. Ambrosetti (2007). "Hearing aids for the treatment of tinnitus." Prog Brain Res 166: 341-345.

Hallam, R. S., S. C. Jakes and R. Hinchcliffe (1988). "Cognitive variables in tinnitus annoyance." Br J Clin Psychol 27 (Pt 3): 213-222.

Heller, A. J. (2003). "Classification and epidemiology of tinnitus." Otolaryngol Clin North Am 36(2): 239-248.

Hiller, W. and G. Goebel (1992). "A psychometric study of complaints in chronic tinnitus." J Psychosom Res 36(4): 337-348.

Kleinjung, T., T. Steffens, J. Strutz, et al. (2009). "Curing tinnitus with a Cochlear Implant in a patient with unilateral sudden deafness: a case report." Cases J 2: 7462.

Langguth, B., R. Goodey, A. Azevedo, et al. (2007). "Consensus for tinnitus patient assessment and treatment outcome measurement: Tinnitus Research Initiative meeting, Regensburg, July 2006." Prog Brain Res 166: 525-536.

Masgoret Palau, E., J. L. Meran Gil, C. Moreno Vidal, et al. (2010). "[Tinnitus and cochlear implantation. Preliminary experience]." Acta Otorrinolaringol Esp 61(6): 405-411.

Mertens, G. D. B., M; Van de Heyning, P (2015). "Cochlear Implantation as a Long-Term Treatment for Ipsilateral Incapacitating Tinnitus in Subjects with Unilateral Hearing Loss up to 10 years." Hearing Research In press.

Van de Heyning, P., A. Gilles, S. Rabau, et al. (2015). "Subjective tinnitus assessment and treatment in clinical practice: the necessity of personalized medicine." Curr Opin Otolaryngol Head Neck Surg 23(5): 369-375.

Van de Heyning, P., K. Vermeire, M. Diebl, et al. (2008). "Incapacitating unilateral tinnitus in single-sided deafness treated by cochlear implantation." Ann Otol Rhinol Laryngol 117(9): 645-652.

von Ilberg, C., J. Kiefer, J. Tillein, et al. (1999). "Electric-acoustic stimulation of the auditory system. New technology for severe hearing loss." ORL J Otorhinolaryngol Relat Spec 61(6): 334-340.

Wewers, M. E. and N. K. Lowe (1990). "A critical review of visual analogue scales in the measurement of clinical phenomena." Res Nurs Health 13(4): 227-236.

Zeng, F. G., Q. Tang, A. Dimitrijevic, et al. (2011). "Tinnitus suppression by low-rate electric stimulation and its electrophysiological mechanisms." Hear Res 277(1-2): 61-66.

Table 1. *Subject demographics. f= female; m= male; l= left and r= right.*

Case	Gender	Implanted ear	Etiology	Age at implantation (YR)	Age at testdate (YR)	PTA_{contra_ear} (dB HL)
EAS_SSD_CASE	f	l	Sudden Deafness	46	51	10
CI_SSD_001	f	l	Hydrops	58	63	28
CI_SSD_002	m	l	Sudden Deafness	63	67	15
CI_SSD_003	f	r	Hydrops	53	63	14
CI_SSD_004	f	l	Hydrops	59	68	29
CI_SSD_005	m	r	Sudden Deafness	22	32	19
CI_SSD_006	f	l	Labirynthitis	38	48	26
CI_SSD_007	f	r	Hydrops	61	65	24
CI_SSD_008	m	r	Sudden Deafness	55	64	15
CI_SSD_009	f	l	Herpes zoster oticus	59	67	25
CI_SSD_010	f	r	Sudden Deafness	44	48	4
CI_SSD_011	m	r	Trauma	34	45	25

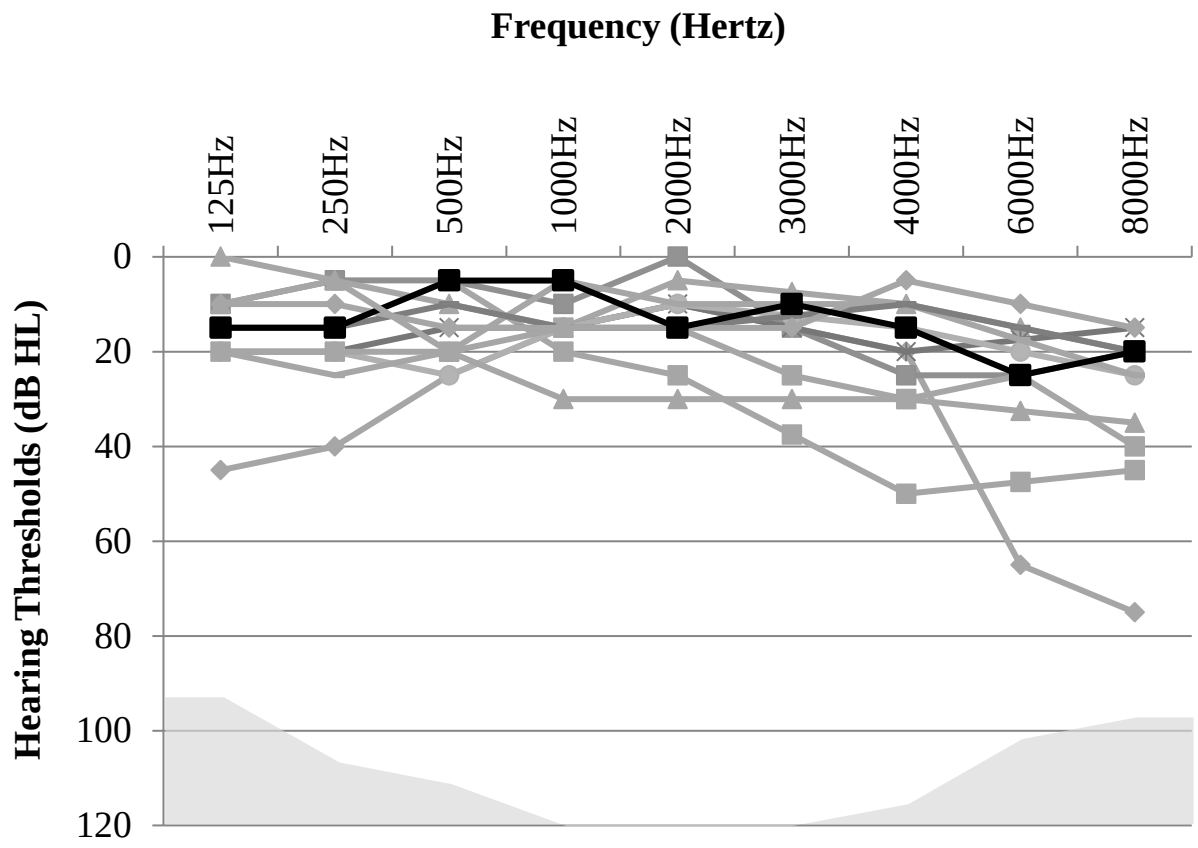

Figure 1A. *Pre-operative individual hearing thresholds of the non-implanted ear. The black line represents the EAS-SSD Subject, the gray lines represent the CI SSD Subjects (n= 11). The shaded area indicates the max. output levels of the audiometer.*

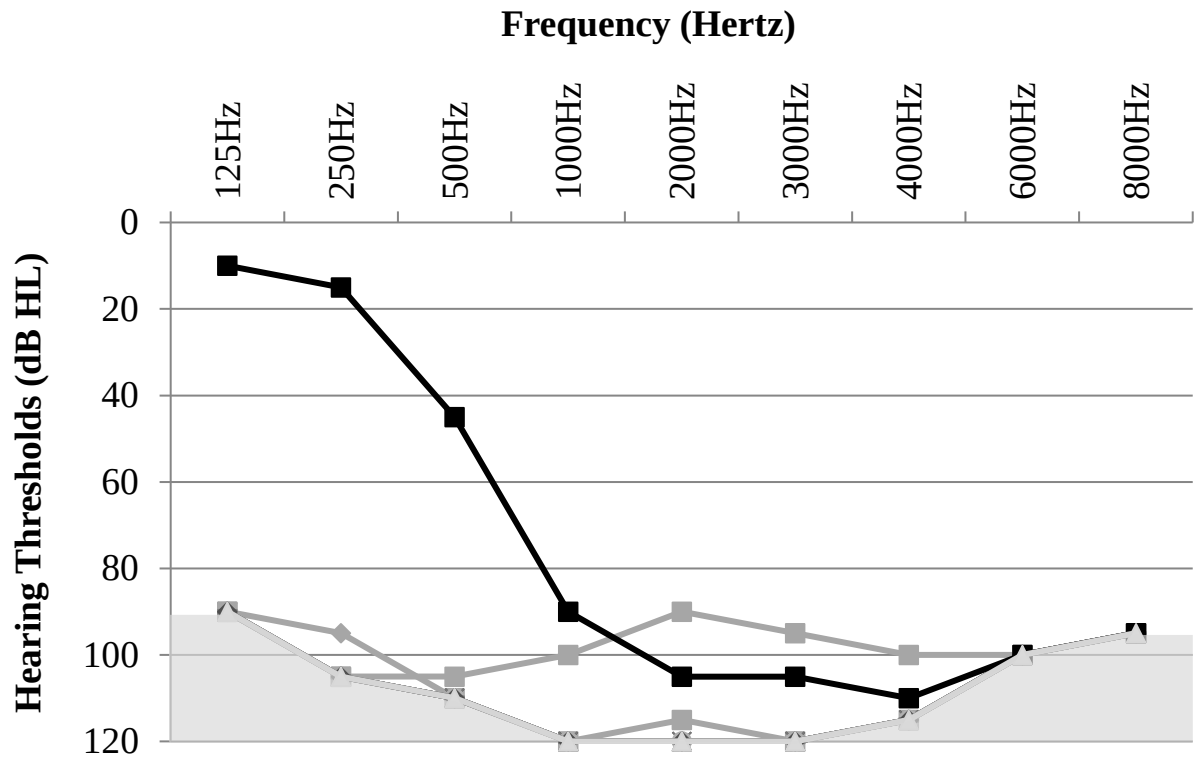

Figure 1B. *Pre-operative individual hearing thresholds of the implanted ear. The black line represents the EAS-SSD CASE, the gray lines represent the CI SSD Subjects (n= 11). The shaded area indicates the max. output levels of the audiometer.*

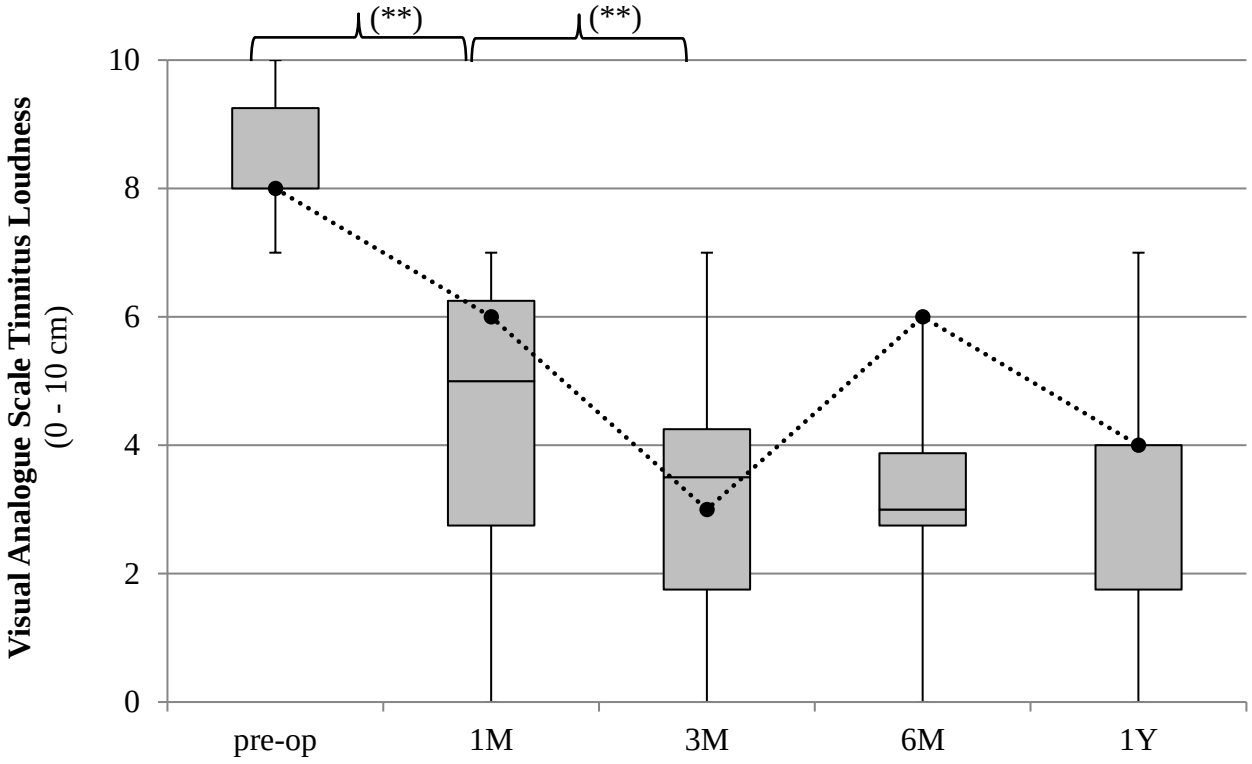

Figure 2. *Boxplots (minimum, quartile 1, median, quartile 3 and maximum) represent the distribution of the VAS scores of the CI-SSD Subjects for the follow-up intervals (pre-operative; 1 month; 3 months; 6 months and 12 months post-operative). Black dots (●) represent the VAS scores of the EAS-SSD Subject. Significant differences ($p < 0.01$) are indicated with an asterisk (**).*

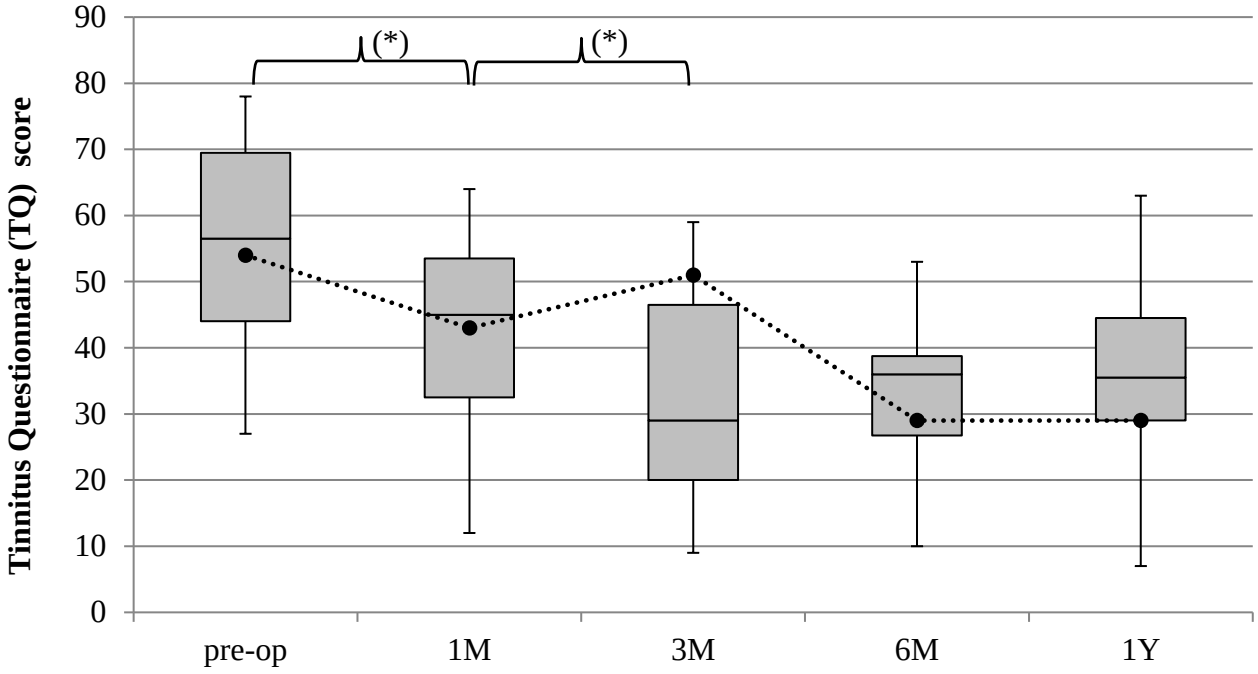

Figure 3. *Boxplots (minimum, quartile 1, median, quartile 3 and maximum) represent the distribution of the TQ scores of the CI-SSD Subjects for the follow-up intervals (pre-operative; 1 month; 3 months; 6 months and 12 months post-operative). Black dots (●) represent the TQ scores of the EAS-SSD Subject. Significant differences ($p < 0.05$) are indicated with an asterisk (*).*