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RESEARCH NOTE

Transcutaneous electrical nerve stimulation (TENS) of upper cervical nerve (C2) for the treatment of somatic tinnitus

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Abstract Somatic tinnitus has been defined as tinnitus temporally associated to a somatic disorder involving the head and neck. Several studies have demonstrated the interactions between the somatosensory and auditory system at the dorsal cochlear nucleus (DCN), inferior colliculus, and parietal association areas. The objective is to verify the effect of transcutaneous electrical nerve stimulation of the upper cervical nerve (C2) in the treatment of somatic tinnitus. As electrical stimulation of C2 increases activation of the DCN through the somatosensory pathway and enlarges the inhibitory role of the DCN on the central nervous system, C2 TENS can be considered for tinnitus modulation. A total of 240 patients in whom tinnitus is modulated by somatosensory events (e.g., tinnitus change with rotation, retro- and antiflexion of neck) or modulated by pressure on head or face were included in this study. Both a real and a sham TENS treatment were applied for 30 min (10 min of 6 Hz, followed by 10 min of 40 Hz and 10 min of sham). Significant tinnitus suppression was found ($P < 0.001$). Only 17.9% ($N = 43$) of the patients with tinnitus responded to C2 TENS. They had an improvement of 42.92%, and six patients had a reduction of 100%.

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Introduction

Tinnitus is a common and disturbing symptom, characterized by the perception of sound or noise in the absence of an auditory stimulus and is therefore also considered an auditory phantom percept (Jastreboff 1990) similar to central neuropathic pain (Moller 2000; Tonndorf 1987). Somatic tinnitus, which is a particular form of tinnitus, has been defined as tinnitus temporally associated to a somatic disorder involving the head and neck (Levine 1999). Typically, an interaction between the somatosensory and auditory systems occurs which makes it possible to modify this type of tinnitus. Neck and orofacial movements, movements of upper extremities, tactile stimulation, changes in gaze, temporomandibular joint disorder, and teeth manipulations have already been reported for modulating somatic tinnitus (Cacace et al. 1999, 1994; Morgan 1992; Salvinelli et al. 2003; Simmons et al. 2008).

Several studies have demonstrated the interactions between the somatosensory and auditory system, either at the dorsal cochlear nucleus (DCN) or at the inferior colliculus (Shore et al. 2000; Szczepaniak and Moller 1993). In animals, it was shown that hyperactivity in the DCN, which is a second-order auditory structure (Shore et al. 2000), correlates with noise-induced tinnitus (Kaltenbach et al. 2004). The DCN receives auditory input from the VIIIth nerve and somatosensory input, directly from ipsilateral dorsal column and spinal trigeminal nuclei (Itoh et al. 1987; Weinberg and Rustioni 1987; Wright and Ryugo 1996; Zhou and Shore 2004) or indirectly via the dorsal raphe and locus coeruleus (Zhang and Guan 2007). Electrical stimulation activates or inhibits cells in the ventral and dorsal division of the cochlear nucleus (Shore 2005; Shore et al. 2003; Young et al. 1995) and can suppress or enhance responses to sound (Shore 2005; Shore et al. 2003).

It was shown that electrical stimulation in the cat DCN yields strong inhibition and weak excitation of DCN principal cells (Davis et al. 1996; Young et al. 1995). It is also known that the pinna and the neck are innervated by the upper cervical nerves (C1–C3), which project to DCN (Abrahams et al. 1984a, b; Hekmatpanah 1961). Interestingly, C2 electrical stimulation evokes large potentials in the DCN, in which stimulation of C2 produces a strong pattern of inhibition and weak excitation of the DCN principal cells (Kanold and Young 2001), analogous to what has been shown for stimulation of DCN principal cells in cats (Davis et al. 1996; Young et al. 1995).

For tinnitus, few to no successful pharmacological treatments exist (Dobie 1999), and conventional or broadband hearing aids are of little benefit (Moffat et al. 2009). Therefore, other treatment modalities have emerged such as rTMS (Khedr et al. 2008; Kleinjung et al. 2005; Londero et al. 2006), tDCS (Vanneste et al. 2010) or cortical implants (De Ridder et al. 2006, 2004).

Another method is electrical suppression of tinnitus by use of transcutaneous electrical nerve stimulation (TENS) (Herraiz et al. 2007). TENS is a non-invasive, very safe method commonly used to reduce acute and chronic pain (Bjordal et al. 2003; Haldeman et al. 2008; Johnson and Martinson 2007). For tinnitus, it was first shown that TENS of the median nerve could modulate the tinnitus percept in some patients (Moller et al. 1992). TENS was then applied to the temporomandibular joint which had an inhibitory effect on 46% of patients with tinnitus ($N = 26$) (Herraiz et al. 2007). Similar results were obtained in a large study of 500 patients with tinnitus (Steenerson and Cronin 2003). In this study, TENS was applied to twenty arbitrarily selected points on the external pinna and tragus of the each ear, which leads a 53% tinnitus improvement.

The objective of the present study is to verify the effect of TENS of the upper cervical nerve (C2) in the treatment of somatic tinnitus. As electrical stimulation of C2 increases activation of the DCN through the somatosensory pathway and enlarges the inhibitory role of the DCN on the central auditory nervous system (Kanold and Young 2001; Young et al. 1995), C2 TENS can be considered for tinnitus modulation.

Methods

A total of 240 patients with tinnitus ($N = 240$, 147 (61.25%) males and 93 (38.75%) females) were entered into this study. The average age was 51.23 (SD = 8.34 years; range 28–68 year). Regarding tinnitus laterality, 63 (26.25%) patients had left-sided tinnitus, 44 (18.33%) patients had right-sided tinnitus, and 133 (55.42%) patients had bilateral tinnitus. Patients were asked also to indicate whether their tinnitus was perceived as a tone, a noise, or both. Regarding tinnitus type, 65 (27.08%) patients presented with pure tone tinnitus, 164 (68.33%) patients had narrow band noise tinnitus, and 11 (4.58%) patients had both pure tone and narrow band noise tinnitus. The mean tinnitus duration was 6.19 years (SD = 7.92).

All prospective participants undergo a complete audiological, ENT, and neurological investigation to rule out possible treatable causes for their tinnitus. Tinnitus matching is performed by presenting sounds to the ear in which the tinnitus is not perceived in unilateral tinnitus, bilaterally in patients with bilateral tinnitus. Technical investigations include MRI of the brain and posterior fossa, pure tone and speech audiometry, and tympanometry. Inclusion criteria were tinnitus modulated by somatosensory events (e.g., tinnitus change with rotation, retro- and antiflexie of neck) or modulated by pressure on head or face. Tinnitus duration in all patients was longer than 6 months.

TENS (Profile TENS, Body Clock Health Care Ltd., UK) can generate a constant current with a pulse rate of 1–200 Hz and an intensity of 0–100 mA. Two silver electrodes were, respectively, placed on the left and right C2 nerves dermatomes (see Fig. 1). The positive electrode was placed ipsilateral to the tinnitus side. For patients with bilateral tinnitus, the positive electrode was placed on the right side. TENS consisted out of 10 min of biphasic rectangular stimulation at 6 Hz, immediately followed by 10 min of stimulation at 40 Hz and sham stimulation. Both real stimulations were applying pulses of 250 µs pulse width. The intensity of the TENS stimulation is slowly increased until a clear sensation of paresthesias was felt by the patient and was subsequently decreased to subthreshold (for most patients, this was around 30 mA). For sham stimulation, the electrodes were placed at the same positions as for the active stimulation, but the simulator was turned on for only 30 s. Thus, participants felt the initial itching/tingling

Fig. 1 Illustration location electrodes

sensation associated with TENS. This method was shown to be sufficient to keep participants blind to direct current stimulation (Gandiga et al. 2006). Each patient received a real and a sham TENS treatment.

Assessment of tinnitus loudness ('How loud is your tinnitus?': 0 = 'no tinnitus' and 10 = 'as loud as imaginable') is analyzed by Visual Analogue Scale (VAS) which was asked before (pre) and directly after (post) TENS stimulation.

Statistical analyses were performed using SPSS (SPSS Inc., Chicago, IL, USA). To verify whether there were differences in tinnitus loudness before and after TENS treatment, a paired *t*-test was performed.

A univariate ANOVA was conducted with tinnitus type (pure tone, narrow band noise or both), tinnitus side (left-sided, right-sided or bilateral), and tinnitus duration as independent variables and the amount of difference between pre and post VAS loudness (=VAS loudness pre–post) as dependent variables.

A logistic regression analysis was conducted to verify whether the independent variables gender, tinnitus type, tinnitus laterality, and tinnitus duration could predict if a patient would respond or not to tDCS treatment. Responders are defined as patients that respond to TENS treatment (VAS pre–VAS post > 0), while non-responders are defined as patients that do not respond to TENS treatment (VAS pre–VAS post ≤ 0). The variables gender, tinnitus type, tinnitus laterality were recode in contrast variables, respectively, gender (woman 1 and man −1), tinnitus type 1 (narrow band noise 1 and pure tone −1), tinnitus type 2 (narrow band noise 1 and pure tone and narrow band noise −1), tinnitus side 1 (left 1 and right −1) and tinnitus side 2 (left 1 and bilateral −1).

Table 1 Mean and standard deviation for gender, tinnitus type, and tinnitus side

	M	SD
Gender		
Male	0.67	1.63
Female	0.49	1.09
Tinnitus type		
Pure tone	0.57	1.02
Narrow-band noise	0.64	1.40
Both	0.00	0.00
Tinnitus side		
Left	0.68	1.44
Right	0.49	1.45
Bilateral	0.56	1.33

Table 2 Logistic regression model: predicting responder versus non-responder from gender, age, tinnitus type, tinnitus laterality, and tinnitus duration

Logistic regression model	Responder versus non-responder		
	B	SE *B*	e^B
Gender	−0.14	0.57	0.87
Tinnitus type 1	19.76	28,420.74	0.01
Tinnitus type 2	19.97	28,420.74	0.01
Tinnitus side 1	0.25	0.52	1.28
Tinnitus side 2	−19.88	9,736.84	0.87
Tinnitus duration	−0.003	0.04	0.99
Constant	−21.18		
χ^2		9.10	

Results

Overall, a significant tinnitus suppression effect ($t = 6.40$, $P < 0.001$) was found when comparing the VAS pre ($M = 6.16$, $SD = 2.18$) with the VAS post ($M = 5.56$, $SD = 2.42$). However, only 17.9% of the patients with tinnitus responded to TENS stimulation and had a mean improvement of 42.92% on the VAS loudness score. Six patients had a reduction of 100%. The worsening rate after therapy was 3.3%. Only six patients perceived suppression on placebo.

An univariate ANOVA on the amount of reduction between pre and post VAS loudness revealed no significant effect for gender ($F = 0.17$, $P = 0.66$ tinnitus type ($F = 1.59$, $P = 0.28$), tinnitus side ($F = 0.08$, $P = 0.93$), and tinnitus duration ($F = 1.32$, $P = 0.25$) (see Table 1).

Logistic analysis verifying whether the independent variables gender, tinnitus type, tinnitus side, and tinnitus duration could discriminate between responders and non-responders yielded no significant effect $\chi^2 = 9.10$, $P = 0.17$ (see Table 2).

Discussion

Suppression of tinnitus by electrical stimulation via preauricular skin, mastoid, eardrum, promontorium, round window, and inside the cochlea has been used clinically since the 1960s and 1970s (Aran et al. 1983; Cazals et al. 1978; Graham and Hazell 1977). Electrical stimulation by use of TENS via the second cervical nerve (C2) can also be a possible option for the treatment of somatic tinnitus. However, as a routine treatment, it is unlikely to be successful in its current form as only 18% of the patients demonstrated a transient suppressive effect (of 43% on average) during the stimulation, and only six patients were tinnitus-free during TENS of the C2 dermatomes. This suppression effect only remains as long as the stimulation lasts. In comparison, other studies showed a suppressive effect from 7 to 60% depending on the current (i.e., direct or alternating) and the location of the electrodes (see (Kapkin et al. 2008) for an overview). This might indicate that there is a high degree of individual variation in patient response to electrical stimulation. Some subtypes of tinnitus might better respond to TENS than others. Previous research already reported that cochlear lesions can be better suppressed by electrical stimulation than cases with retrocochlear lesions (Okusa et al. 1993). Yet, our results reveal that the amount of transient tinnitus suppression obtained by TENS is independent of tinnitus type (pure tone or narrow band noise), tinnitus side (unilateral or bilateral), and tinnitus duration as well as gender, which makes it difficult to decide who might benefit from C2 TENS and who not. Somatic tinnitus can have multiple etiologies (Herraiz et al. 2007), and depending on the origin of the somatic tinnitus, differences in suppression effect might be found in future studies.

Our research findings are in accordance with the hypothesis that electrical stimulation of the upper cervical nerve (C2) increases activation of the DCN through the somatosensory pathway. Previous research already illustrated that electrical stimulation increases the inhibitory role of the DCN on the central auditory nervous system (Kanold and Young 2001; Young et al. 1995). The DCN receives auditory input from the VIIIth nerve and somatosensory input, directly from ipsilateral dorsal column and spinal trigeminal nuclei (Itoh et al. 1987; Weinberg and Rustioni 1987; Wright and Ryugo 1996). The upper cervical nerves C2 project to spinal trigeminal nuclei (Abrahams et al. 1984a, b; Hekmatpanah 1961), and C2 electrical stimulation evokes large potentials in the DCN. Stimulation of C2 produces a pattern of inhibition of the DCN principal cells (Kanold and Young 2001), a hypothetical mechanism for suppressing tinnitus. This is in accordance with previous animal studies demonstrating that stimulation can inhibit (as well as enhance) responses to sound (Shore 2005; Shore et al. 2003).

However, somatosensory–auditory interactions might also occur at the inferior colliculus (Aitkin et al. 1978; Dehmel et al. 2008; Jain and Shore 2006; Szczepaniak and Moller 1993) or parietal association areas (Leinonen et al. 1980) and could possibly also be involved in the clinical suppressive effect. Functional neuroimaging studies with C2 TENS should help elucidate which pathophysiological mechanisms are involved.

The efficacy of TENS of the upper cervical nerve in somatic tinnitus does not rule out that this treatment can also be used for non-somatic tinnitus with the same protocol. In a recent study, it was suggested that the development of tinnitus (somatic or non-somatic) is likely associated with functional β glycine receptor subunits changes in DCN fusiform cells (Wang et al. 2009). As DCN changes it might be involved in the development of tinnitus in general. As such, it is possible that TENS of the DCN via C2 might also modulate non-somatic tinnitus.

Although this study was placebo-controlled, only a very small amount of patients (6%) had a placebo effect. This could be due to the fact that some patients did feel paresthesias, even though the stimulation intensity was set to be subthreshold for sensory perception (Kapkin et al. 2008). Some authors argue that local infiltration with anesthesia at the electrode site could overcome this latter problem (Kapkin et al. 2008). However, it is known that, for example, lidocaine injection can have an important suppressive influence on tinnitus perception as well, which makes the analysis even more difficult (Darlington and Smith 2007; Savastano 2004; Trellakis et al. 2007).

In conclusion, TENS of the C2 dermatoma improves 18% of our patients with somatic tinnitus transiently with 43% tinnitus reduction on average, with a significant reduction on VAS scores during and immediately after treatment.

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