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REVIEW

Somatosensory Tinnitus: Recent Developments in Diagnosis and Treatment

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Abstract

Somatosensory tinnitus (ST) is a type of tinnitus where changes in somatosensory input from the head-neck area are one of the influencing factors of a patient's tinnitus. As there are often several influencing factors, identifying a clear somatosensory influence on an individual patient's tinnitus is often a challenge. Therefore, a decision tree using four clinical criteria has been proposed that can help diagnose ST with an accuracy of 82.2%, a sensitivity of 82.5%, and a specificity of 79%. Once correctly diagnosed, patients can be successfully treated using a musculoskeletal physical therapy treatment. This type of treatment can either be directed at cervical spine dysfunctions, temporomandibular disorders, or both and consists of a combination of counseling, exercises, and manual techniques to restore normal function of the cervical spine and temporomandibular area. Other techniques have been suggested but need further investigation in larger RCTs. In most cases, ST treatment shows a decrease in tinnitus severity or loudness, but in rare cases, total remission of the tinnitus is achieved.

Keywords Tinnitus · Somatosensory · Somatic

Background

Tinnitus, the perception of sound without external acoustic stimulation, occurs in 10 to 15% of adults [1]. Tinnitus is a symptom often related to hearing loss or noise trauma, but it can also be linked to depression, anxiety, or excessive stress [1]. Additionally, tinnitus can be influenced by somatosensory input from the cervical spine and temporomandibular area, then called somatic or somatosensory tinnitus (ST) [2, 3].

On a pathophysiological level, almost all cases of tinnitus appear to be associated with some degree of peripheral hearing loss, either resulting in impaired hearing or involving abnormal supra-threshold sound processing, which is often referred to as "hidden hearing loss" [4]. Despite this strong link between tinnitus and peripheral hearing loss, the brain is believed to play a key role in the pathophysiology of tinnitus [5]. More specifically for ST, a pathophysiological model was presented where brainstem connections between somatosensory and auditory nuclei are suggested as the means by which changes in somatosensory afference can alter the loudness and pitch of an existing tinnitus or can even cause tinnitus [6]. Since the presentation of this model, several studies in animals and humans have provided evidence for the involvement of cortical networks.

Studies in animal models identified projections from somatosensory neurons to the ventral and dorsal cochlear nucleus (CN) and inferior colliculus (IC), which are involved in auditory processing [7, 8] (see Fig. 1 for a comprehensive overview of all pathways retrieved from animal models). Through these projections, somatosensory afference from the head and neck region is able to alter both firing rate and synchrony of firing of CN neurons. Changes in firing rate are suggested to be associated with tinnitus loudness fluctuations, whereas changes in neural firing synchronicity are linked to alterations in tinnitus pitch [7]. Stimulation of cervical nerves in cats has shown that input from mechanoreception and proprioception has the largest influence on CN activity [9]. Nociception, on the other hand, does not appear to have a direct influence on CN activity since nociceptive projection cells are located in areas that do not directly project to the CN [10].

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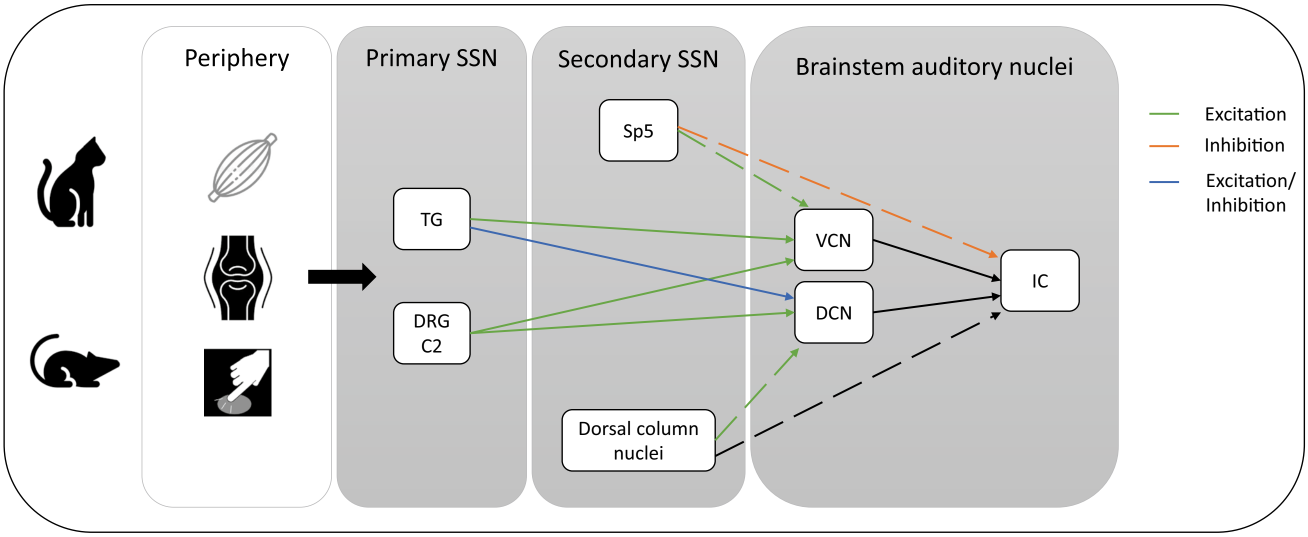

Fig. 1 Animal model of auditory–somatosensory pathway interactions [7–10, 12, 13]. TG, trigeminal ganglion; DRG, dorsal root ganglion; Sp5, spinal trigeminal nucleus; VCN, ventral cochlear nucleus; DCN, dorsal cochlear nucleus; IC, inferior colliculus

These findings suggest that tinnitus alterations in patients with ST are not caused by pain sensation but by changes in proprioceptive or mechanoreceptive input linked to increased muscle tension or restricted mobility in the neck or jaw region.

Other animal research using light and electron microscopy suggests that the above-mentioned projections from the somatosensory neurons to the CN are an excitatory (glutamatergic) pathway [10–13]. Projections from the trigeminal ganglion can have both an excitatory and inhibitory (GABAergic) effect on dorsal CN activity [14]. Projections from the spinal trigeminal nucleus to the IC, on the other hand, seem to be mostly inhibitory [14, 15]. These findings suggest that, in most cases, increased activity in the connective fibers between the somatosensory nuclei and CN will cause an increase in firing rate in the CN.

In humans, Lanting et al. [16] identified activation differences restricted to the CN and IC between patients with temporomandibular-related ST and participants without tinnitus, assessed with functional magnetic resonance imaging during jaw protrusion, indicating the abovementioned mechanisms are also present in humans. Through this mechanism, the somatosensory system may cause tinnitus and/or alter the pitch or loudness of an existing tinnitus [7].

Where ST was originally described as a subtype of tinnitus, nowadays, tinnitus experts agree that in most patients, tinnitus has a multifactorial origin with a multitude of potential influencing factors [17–19]. Consequently, ST can be defined as tinnitus that is influenced by the cervical or temporomandibular somatosensory system.

This review aims to give an overview of the diagnostic process and treatment possibilities for patients with ST.

Somatic Tinnitus Diagnosis

Since the first papers in the 1990s mentioned the possible influence of the somatosensory system on tinnitus

Criteria on tinnitus modulation
The patient is able to modulate the tinnitus by voluntary movement of the head, neck, jaw or eyes
The patient is able to modulate the tinnitus by somatic maneuvers
Tinnitus is modulated by pressure on myofascial trigger points

Tinnitus characteristics
Tinnitus and neck or jaw pain complaints appeared simultaneously
Tinnitus and neck/jaw pain symptoms aggravate simultaneously
Tinnitus is preceded by a head or neck trauma
Tinnitus increases during bad postures
Tinnitus pitch, loudness and/or location are reported to vary
In case of unilateral tinnitus, the audiogram does not account for unilateral tinnitus

Accompanying symptoms
Tinnitus is accompanied by frequent pain in the cervical spine, head or shoulder girdle
Tinnitus is accompanied by the presence of pressure tender myofascial trigger points
Tinnitus is accompanied by increased muscle tension in the suboccipital muscles
Tinnitus is accompanied by increased muscle tension in the extensor muscles of the cervical spine
Tinnitus is accompanied by temporomandibular disorders
Tinnitus is accompanied by teeth clenching or bruxism
Tinnitus is accompanied by dental diseases

Fig. 2 Diagnostic criteria for somatosensory tinnitus [17]

complaints [2, 3, 6], several papers have described ways to identify these patients.

In 2011, Sanchez et al. [20] proposed a set of diagnostic criteria to help recognize patients with ST in clinical practice. These criteria include the presence of recurrent pain episodes in the head, neck, or shoulder girdle and a temporal coincidence of the appearance of both tinnitus and pain complaints [20]. Others state that so-called *somatic modulation*, where tinnitus is momentarily changed during voluntary movements or specific resistance tests, is essential in diagnosing ST [21, 22].

In 2018, a new set of diagnostic criteria was published based on a modified Delphi process with a consensus meeting [17]. Instead of asking the participating experts to suggest criteria from scratch, they were asked to review a *long list* of potential diagnostic criteria for ST [17].

This process resulted in a set of 16 diagnostic criteria, subdivided into three categories (Fig. 2) [17]. These criteria came with some sidenotes from the consensus meeting panel. First, it was stated that although somatic modulation, especially through voluntary movements, was recognized as an important criterion, *the absence of this ability does not rule out ST* [17]. Therefore, somatic modulation should not be used as a single "yes or no" criterion to diagnose ST [17]. Second, the authors suggested using the criteria related to the presence of, for instance, neck pain or temporomandibular disorders with some prudence, as these complaints can also co-exist with tinnitus without there being a causal relation [23]. Although their presence strengthens the ST diagnosis in case it is combined with another criterion, such as *tinnitus and neck or jaw pain complaints appeared simultaneously* [17].

After publication of the new set of 16 criteria, the diagnostic value of all criteria separately was investigated in a group of 8221 participants with and without somatic influence on their tinnitus [24]. This analysis showed that the *simultaneous onset or increase and decrease of both tinnitus and pain complaints* have the highest positive likelihood ratio (LR) (6.29 and 10.72, respectively). These two criteria are thus the strongest to use as a single criterion.

On the contrary, a patient's ability to modulate their tinnitus through voluntary movements or pressure on the head or neck appeared to have very little diagnostic value when used as a single criterion (LR + : 1.81 and LR − : 0.82) [24].

Additionally, the mere presence of neck or jaw complaints in patients with tinnitus was shown to have limited additional value as well, as the presence of these criteria only increased the probability of a ST diagnosis to about 50% [24].

In general, the analysis showed that the specificity of the 16 criteria to diagnose ST was high, but the sensitivity was rather low [24] (see Fig. 3 for more details). This implicates a relatively high risk of false negatives, which is not ideal as we do not want to leave these patients without a referral for a potentially effective treatment.

To solve this risk of false negatives, the authors advise using a combination of criteria before diagnosing a patient with ST. A follow-up study was completed to find the most ideal combination of diagnostic criteria to have the highest accuracy, sensitivity, and specificity.

Based on data from 7981 participants with tinnitus, a decision tree for ST diagnosis was constructed [25]. The decision

Fig. 3 Diagnostic value of diagnostic criteria for somatosensory tinnitus [24]

Diagnostic criterion	Sensitivity	Specificity	+ LR	- LR	Pre-test probability	+ Post-test probability	- Post-test probability
Modulation by voluntary movements	32	82	1,81	0,82	0,26	0,39	0,23
Simultaneous onset of tinnitus and neck/jaw pain	19	97	6,29	0,83	0,26	0,69	0,23
Co-variation of tinnitus and neck/jaw pain	24	98	10,72	0,78	0,26	0,79	0,21
Influence of posture	15	98	6,04	0,87	0,26	0,68	0,24
Bruxism	29	85	1,93	0,84	0,26	0,41	0,23
Tension in neck extensor muscles	48	81	2,59	0,63	0,26	0,48	0,19
Trigger points	35	90	3,60	0,71	0,26	0,56	0,20
Variation in pitch/loudness/ location	41	73	1,49	0,81	0,26	0,35	0,22
Neck pain	48	82	2,73	0,63	0,26	0,49	0,18
Head or neck trauma	14	95	3,13	0,90	0,26	0,53	0,24
Diagnosed TMD	24	92	3,13	0,83	0,26	0,53	0,23
Dental problems	15	89	1,43	0,95	0,26	0,34	0,25

tree includes four of the sixteen original criteria: *tinnitus and neck/jaw pain increase/decrease simultaneously*, *tension in suboccipital muscles*, *somatic modulation*, and *bruxism*. The model presented in Fig. 4 has an accuracy of 82.2%, a sensitivity of 82.5%, and a specificity of 79% [25].

Somatic Tinnitus Treatment

Musculoskeletal Treatment

Currently, most ST treatment approaches are based on techniques that are mainly applied by physiotherapists or in chiropractic or osteopathic care, depending on regional differences. The main rationale for using these techniques in patients with somatosensory tinnitus is to normalize somatosensory input. In patients with somatosensory tinnitus, this somatosensory afference is often altered by increased muscle tension or restricted movement in the upper cervical spine or temporomandibular joint. Specific techniques are then used to decrease muscle tension and increase mobility and stability so that somatosensory afference will be restored and tinnitus perception decreases. The choice of specific techniques will largely depend on the dysfunction that is found in an individual patient. Therefore, somatosensory tinnitus management should be seen as a patient-centered therapy that should be tailored to the specific patient's needs.

For cervical spine treatment, clinical practice guidelines [26, 27] advise a combination of techniques to restore cervical spine function and reduce pain complaints. Primarily, counseling techniques are used to improve the patient's knowledge about neck pain and to advise the patient towards good posture and movement habits. Additionally, exercises are recommended to improve the strength, coordination, and endurance of the stabilizing neck and shoulder girdle muscles. Training these small muscles, which are located close to the vertebrae, will not only increase cervical spine stability but will also result in long-term reduction of excessive tension in the larger, more superficially located muscles that are often involved in somatosensory tinnitus.

In addition to the core content of counseling and exercises, other techniques can be added depending on the neck dysfunctions that are most prominent in an individual patient. As such, manual mobilizations or manipulations can be used to improve cervical spine mobility when needed. Other techniques, such as ischemic pressure or dry needling to deactivate myofascial trigger points, can also be included in this approach, as long as they are used to support the effect of the core content.

For the treatment of temporomandibular disorders (TMD), three systematic reviews [28–30] show that a combination of exercises and manual techniques is effective. Exercises comprise passive and active stretching of the masticatory muscles and postural exercises to improve the head and neck posture. Myofeedback can be used during exercises to guide patients while relaxing their masticatory muscles. Manual techniques comprise manual mandibular traction or translation and myofascial release techniques of the masticatory muscles. Apart from local treatment of the temporomandibular area, adding cervical spine mobilizations and exercises is recommended when clinical investigation shows additional dysfunctions in the cervical spine.

Apart from the combination of exercises and manual techniques, TMD treatment should also include counseling to address the underlying causes of TMD. Often advice on mouth habits (bruxism, biting nails, chewing gum, etc.), stress reduction, and sleep hygiene will be added. As bruxism is often related to TMD, unlearning clenching or grinding habits will be essential in TMD treatment. In case of nighttime bruxism, occlusal splint therapy can be added. When stress reduction is needed, relaxation therapies such as mindfulness and breathing exercises can be added to the treatment.

In previous years, seven studies [31–37] were published that investigated such a patient-centered multimodal musculoskeletal approach. All studies used a combination of techniques and exercises to treat the neck and/or jaw region according to the current state-of-the-art and tailored the exact content of the therapy to the patient's specific dysfunctions. Neck or temporomandibular disorder counseling, to advise patients in controlling their neck or jaw pain complaints, is always part of such a multimodal approach. Additionally, techniques are applied to decrease muscle tension in the neck or masticatory muscles. These techniques can be passive, such as ischemic pressure techniques or dry needling on myofascial trigger points, but active stretching exercises are also frequently used. Additionally, selective strengthening of deep neck flexor and extensor muscles is often used to achieve a long-term reduction in muscle tension of the trapezius and sternocleidomastoid muscles. Furthermore, manual mobilizations or manipulations of the cervical spine and temporomandibular joint are often used to treat limited mobility.

In patients with neck-related somatosensory tinnitus, this approach showed a significant decrease in tinnitus functional index (TFI) score after 6 weeks of treatment ($p = 0.04$) [33] and a significant decrease in VAS for tinnitus loudness ($p = 0.01$) after a maximum of 12 treatment sessions [34]. Additional analysis showed that patients whose tinnitus increases during episodes of neck pain or certain postures and patients with low-pitched tinnitus were more likely to benefit from this type of treatment [38].

In patients with primary temporomandibular-related ST, the multimodal approach showed a significant decrease in TFI score after 9 weeks of treatment in 80 patients ($p < 0.001$) [35]. Similar results were found in two other studies, showing a significant decrease in VAS-loudness ($p < 0.001$),

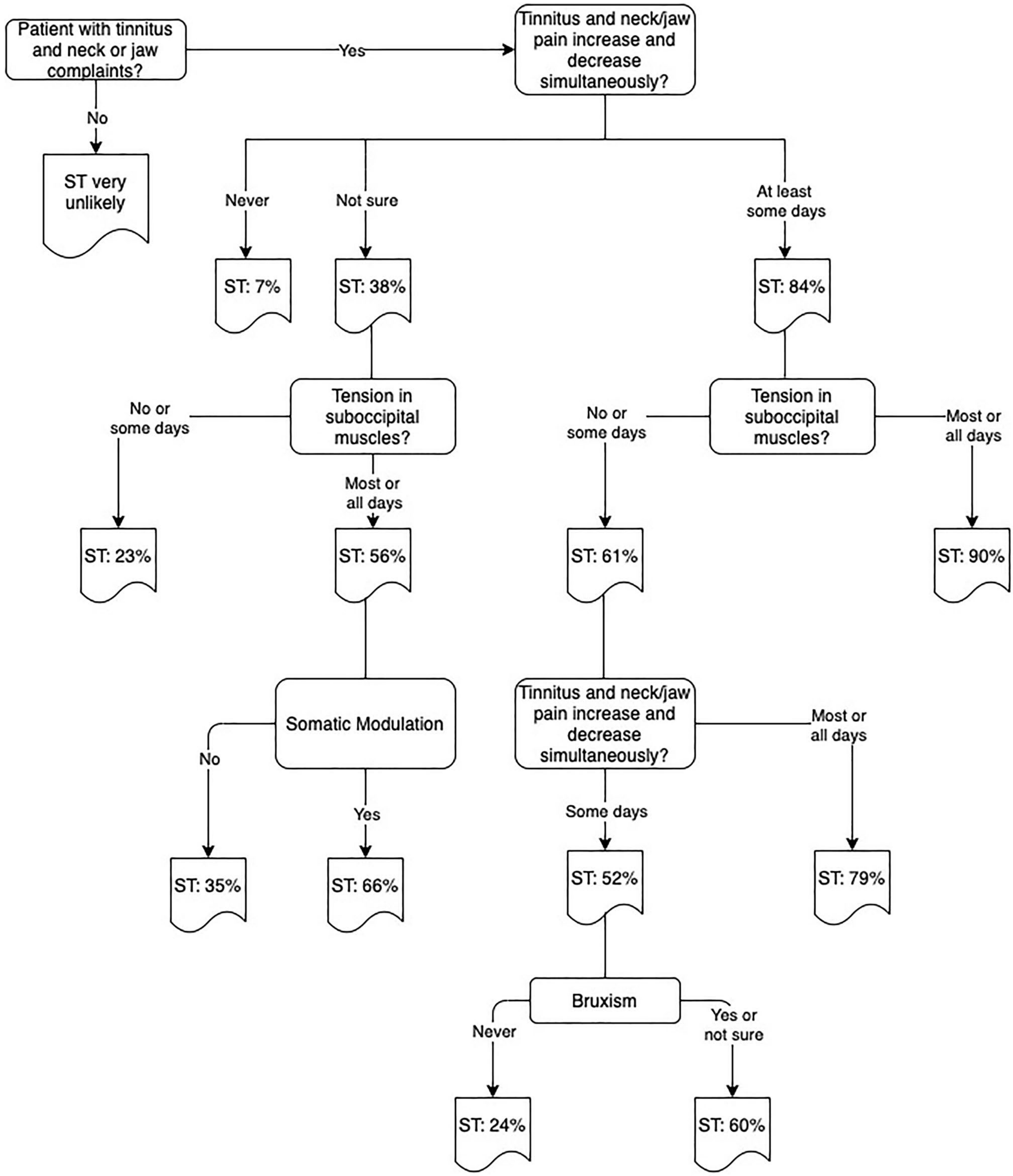

Fig. 4 Rapid screening for somatosensory tinnitus tool [25]

VAS-annoyance ($p < 0.001$), and Tinnitus Handicap Inventory (THI) ($p < 0.001$) in 31 patients [31] and a significant decrease in VAS-severity ($p < 0.001$) in 61 patients [32].

Apart from the multimodal approach, specific musculoskeletal techniques have also been studied as single treatment options for somatosensory tinnitus [39–42].

Atan et al. [39] investigated the effect of Kinesiotape application on the sternocleidomastoid, upper trapezius, and levator scapulae muscles in 15 patients with neck-related somatosensory tinnitus. Kinesiotape is a type of elastic tape that is applied to decrease muscle tension or provide proprioceptive input. The use of this tape on all three muscles resulted in an average decrease in THI score of 13.06 points ($p = 0.001$).

Four other studies used myofascial trigger point deactivation techniques on muscles in the head-neck region as a way to decrease muscle tension. Rocha et al. [42] treated 37 patients with somatosensory tinnitus using ischemic pressure to deactivate the myofascial trigger points. They showed a significant decrease in THI and VAS-annoyance after 5 sessions ($p < 0.001$).

Three other studies investigated dry needling, a technique that uses acupuncture needles for myofascial trigger point deactivation. All studies showed good effects of dry needling on numerical rating scale (NRS) scores for tinnitus severity [40], NRS for tinnitus loudness [43], and THI [37, 43] in patients with ST.

Finally, Wu et al. [41] showed a decrease of 44 point on the THI after deep neck flexor exercises in one case of neck-related somatosensory tinnitus.

Other Management Techniques

Apart from the studies on musculoskeletal management of somatosensory tinnitus, other techniques to normalize somatosensory afference have been investigated. It must be noted that these treatments were often investigated in small samples without a control group and risk of bias of these studies is high. Some of them have not been repeated in the literature, so the effect needs to be confirmed in larger controlled studies before general use can be recommended.

Two studies used transcutaneous electrical nerve stimulation (TENS) as a comparison to musculoskeletal treatment of the cervical spine. One study comparing 2 groups of 20 patients showed similar significant decreases in THI score after TENS treatment of the cervical spine then after cervical spine manipulation [44]. As second non-randomized trial showed significant improvement on a self-developed questionnaire when comparing the effect of cervical spine exercises to TENS applied to the ear in two groups of 40 patients [45]. No significant differences between groups were found in both studies.

One case study showed positive effects of intermittent cervical collar application (15 to 30 min, 3–5 times a day), with complete tinnitus remission within 4 weeks [46]. This remission lasted for 5 months. Afterward, the tinnitus slightly resurged occasionally but disappeared again after short-term application of the cervical collar (15 min once every 2–4 weeks).

In 2005, one study reported the use of subcutaneous botulinum toxin type A injections around the ear for treatment in patients with unilateral or bilateral non-pulsatile tinnitus [47]. The author's rationale for using these injections as a treatment for tinnitus was the blockage of autonomic pathways [47]. This study showed a significant decrease in average THI scores from baseline to 4 months after the injection in a group of 26 patients. No significant decrease was found in the group receiving a placebo injection. The authors indicated that further research was necessary to confirm these results. Unfortunately, no additional studies have been published on the topic in the meantime.

Another study used a cervical epidural steroid injection at level C4 to reduce tinnitus intensity by 75% in one patient [48]. This effect persisted for 5 weeks; hereafter, tinnitus intensity gradually increased again to get back to baseline after another 9 weeks. The authors hypothesize that the observed effect of the injection is a result of a steroid-induced reduction in afferent signaling from the cervical region, resulting in decreased neural activity along the auditory-somatic pathway [48].

Contrary to most techniques that have been suggested for the management of somatosensory tinnitus, Marks et al. [49] proposed a technique to influence the medullary connection between the auditory and somatosensory pathways in a more direct way. The combination of auditory and electrical vagus nerve stimulation showed a significant reduction in TFI score in a group of 20 patients with unilateral pure-tone tinnitus that could be modulated by one or more somatic maneuvers. A larger study using the same technique was recently published, showing a clinically relevant decrease of at least 13 points on the TFI in 65% of a group of 99 patients [50]. Additional studies are needed to confirm these results and to investigate the effect of this treatment in a less-restricted sample of patients with somatosensory tinnitus.

Apart from the therapy options that are directed at normalizing somatosensory input or influencing the medullary auditory-somatosensory connection, one study investigated the effect of tinnitus retraining therapy (TRT) in patients with somatosensory tinnitus [51]. Patients underwent a 3-month TRT protocol, including daily use of white noise generators with or without amplifications, combined with four structured counseling sessions. An average decrease in THI score of 34.95 points was found ($p < 0.05$).

Conclusion

Somatosensory tinnitus, where changes in the somatosensory afference have an influence on the tinnitus pitch or loudness, can be recognized using the set of 16 diagnostic criteria published in 2018. As a single criterion, the *Tinnitus and neck/jaw pain increase/decrease simultaneously* criterion has the most value. But using the combination of four criteria presented in the decision tree will enable clinicians and researchers to recognize patients with ST with higher accuracy, sensitivity, and specificity.

Once diagnosed, ST can be successfully treated using a variety of techniques. Currently, musculoskeletal treatment of the cervical spine and temporomandibular area has the highest level of evidence. Other techniques have been suggested but need further investigation in large RCTs, as their level of evidence is currently low. Mostly, somatosensory tinnitus treatment shows a decrease in tinnitus severity or loudness, but in rare cases, total remission of the tinnitus is achieved.

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