A comparative study of audiology and cone beam computed tomography in TMD patients with otological symptoms through occlusal splint therapy

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INTRODUCTION: *To investigate the changes of audiological tests and the cone beam computed tomography (CBCT) measurements of temporomandibular joint (TMJ) and middle-inner ear structure after occlusal splint therapy in temporomandibular disorders (TMD) patients with otological symptoms, and explore the etiological mechanism between TMD and otological symptoms.*
METHODS: *The 25 subjects aged 18 to 40 years who diagnosed with TMD combined the otological symptoms enrolled in the study.They all had received orthodontic treatment in the outpatient clinic of the orthodontic department in Beijing Stomatological Hospital. All the subjects underwent the audiological tests of pure tone audiometry (PTA) and CBCT before and after the occlusal splint therapy.*
RESULTS: *After the stabilization occlusal splint therapy, subjects with improvement or complete remission in TMD and otological symptoms accounted for 84% and 80% in all subjects respectively. There were statistically differences in the distances between condylar center (CoC) and sella (S) in sagittal and vertical directions before and after treatment, and statistically difference between ATM and S in sagittal direction. The threshold of PTA at 8000Hz were negatively correlated with the sagittal displacement of condyle and positively correlated with the coronal displacement of condyle. The thickness of top 1/3 of anterior wall of tympanum in sagittal were positively correlated with the threshold of PTA at 4000Hz.*
CONCLUSION: *The changes in the TMJ position through occlusal splint therapy might cause the changes in structure of middle-inner ear, which might be one of the reasons for the improvement in otological symptoms.*

KEY WORDS: Audiology, CBCT, Otological symptoms, TMD

Introduction

Temporomandibular disorders (TMD) is a collective term which involves a range of musculoskeletal system disorders affecting the temporomandibular joint (TMJ) and the masticatory muscles [1].

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The most common otological symptoms such as otalgia, tinnitus, ear fullness and vertigo are often coexist with the presence of TMD [2-4], but with little scientific basis on the predisposition, occurrence and development of TMD [2]. In the audiological findings, Pekkan G et al[5] revealed a significant difference between TMD group and the normal control group. In contrast, other researchers have found that audiological test results of the subjects are within the normal range of hearing thresholds [3,6].
On account of the middle-inner ear tructure is adjacent to TMJ, CBCT can observe and analyze the structure of the otosteon and cochlea, and better than multi-detector CT (MDCT) to some extent [7].
Inspite of the aetiology mechanism between the TMD and otological symptoms remains unknown [3,8], there are

still a number of studies which have been found that improvement in otological symptoms occurs after treatment for TMD [9,10].
The aim of this study is to analyze the changes of audiological tests to evaluate the auditory functions, and to assess the structure of TMJ and middle-inner ear using CBCT in the patients with TMD before and after occlusal splint therapy. To investigate the cause of the improvement in otological symptoms after treatment of the TMD and further explore the etiological mechanism between TMD and otological symptoms.

Material and Methods

The 25 subjects enrolled in the study who had received orthodontic treatment in the outpatient clinic of the orthodontic department in Beijing Stomatological Hospital. The subjects included 7 males and 18 females, whose ages rang from 18 to 40 (mean 24.6±6.4).
The subjects with clinical signs and symptoms consisted of myogenous pain, TMJ arthralgia, abnormal joint movement, clicking of joint and headache attributed to TMD, and at least one of the otological symptoms of otalgia, tinnitus, ear fullness and vertigo. The criteria of inclusion include: good general health, basically complete and symmetrical dentition and arch, otological symptoms without a definite cause, no hearing loss, no oral and maxillofacial neck trauma or treatment in the past 6 months, no cognitive deficit, no systemic diseases such as diabetes, hypothyroidism, hypertension [6]. The clinical examination of the TMJ and ear by the same orthodontist and otolaryngologist who were properly trained and calibrated. Experienced examiners conducted a comprehensive review of the study.

Treatment and assessment

The prepared stabilization occlusal splint [11] was put into the maxillary teeth of the subjects, and ground the occlusal splint to make the buccal tip of the mandibular tooth were in uniform contact with it. Subjects were asked to wear the occlusal splint throughout the day and ground the occlusal splint gradually. Criteria for the end of treatment: Measurements of condyle displacement (MCD) showed that the condyle position was stable during three consecutive follow-up visits [12]. The occlusion was stable and the forward and lateral mandibular movement was repeatable.
TMD and otological symptoms assessed before and after the treatment by audiological test, patient's self-report such as aural fullness grading [13], indexes measurement as the Tinnitus Handicap Inventory (THI) [14], the Dizziness Handicap Inventory (DHI) [15] and Visual Analogue Scale.

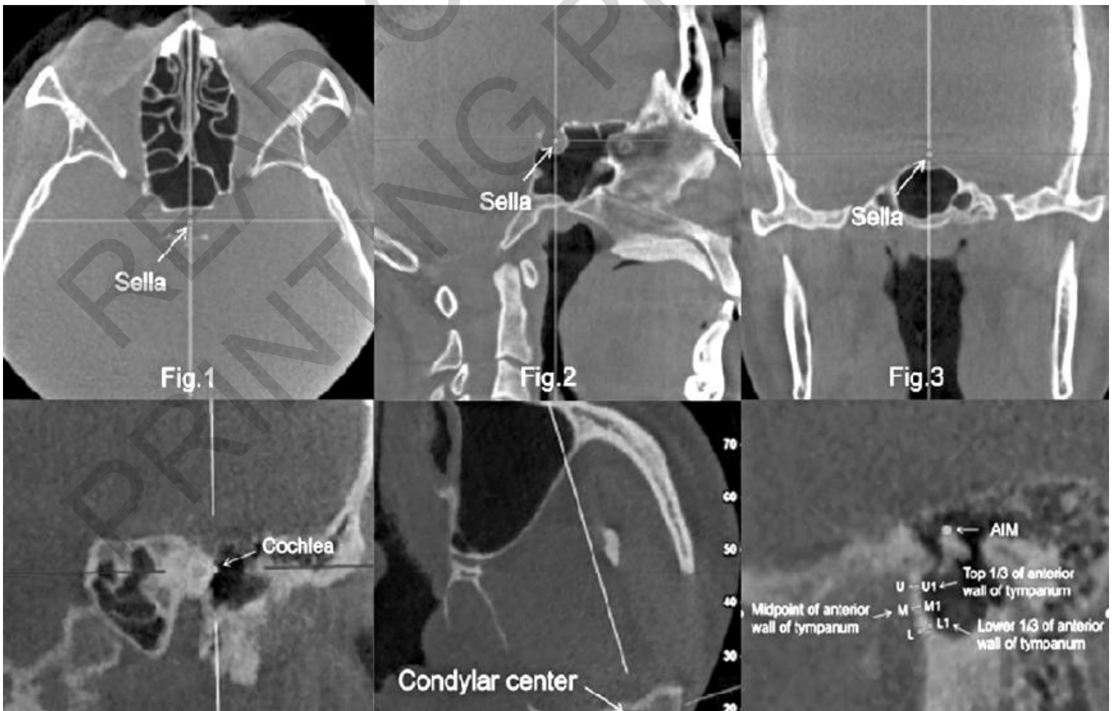

Fig. 1: A) The middle sagittal plane; B) The standard horizontal plane; C) The sella coronal plane; D) Cochlea; E) The condylar center. F: The AIM and anteiror wall plane of the tympanum.

CBCT Examination

All the subjects underwent CBCT without wearing occlusal splint before and after the occlusal splint therapy.

CBCT (Newtom VGi, Italy) scan: with scan parameters set at 110 kV, 15.1 mA, 3.6 sec with field of view 19 cm × 14 cm, and scan slice thickness of 0.25 mm. Subjects were standing upright with Frankfurt horizontal (FH) plane of head position parallel to the floor and closing the mouth into maximum intercuspal position with nose breathing naturally. NNT Viewer 5.3 software was used for image reconstruction and processing.

Determine the location plane: We corrected the position of the skull in three dimensions by adjusting the cursor [16]. The standard horizontal plane (SHP) was the plane passing through the left and right suborbital points and the highest point on the upper margin of the right external acoustic canal. The middle sagittal plane (MSP) was the plane perpendicular to SHP passing through both the skull base point and nasion point. The sella coronal plane (SCP) was the plane perpendicular to both MSP and SHP passing through the sellar point (Fig. 1).

Determine the measurement plane and mark point: (1) The maximum axial surface of condyle: The plane was parallel to SHP. The layer scanning from the apex of condyle to the sigmoid notch. When the transverse area of the lower condyle was less than this layer, it was regarded as the maximum axial surface of condyle. (2) Anteiror wall plane of the tympanum: The first layer of the tympanum scute completely disappeared from front to back on the MSP. (3) Condylar center (CoC) point: The central point of the maximum axial surface of the condyle. (4) Articulatio incumalleius (AIM) point: The top point of the AIM. (5) Cochlea point: The outermost point on the SCP from front to back when the first cochlea spiral appeared (Fig. 1).

Measuring project: (1) The position of condyle relative to the structure of the skull base: The distance from CoC to SHP, MSP, SCP (CoC-SHP, CoC-MSP, CoC-SCP). (2) The position of AIM relative to the structure of the skull base: The distance from AIM to SHP, MSP, SCP (AIM-SHP, AIM-MSP, AIM-SCP). (3) The position of cochlea relative to the structure of the skull base: The distance from cochlea to SHP, MSP, SCP (cochlea-SHP, cochlea-MSP, cochlea-SCP). (4) The thickness of anterior wall of tympanum: Divided the anterior wall of tympanum into three equal parts, and made vertical line of anterior wall of tympanum through the midpoint of three parts respectively, the points of intersection were U, U1, M, M1, L and L1. The distances from U to U1 represented the thickness of top 1/3 of the anterior wall of the tympanum (U-U1), M to M1 represented the thickness of midpoint 1/3 of the anterior wall of the tympanum (M-M1), and L to L1 represented the thickness of lower 1/3 of the anterior wall of the tympanum (L-L1).

Table I - *The comparison of pure tone air condition thresholds before and after treatment at every frequencies in 50 ears.*

Group	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
Before treatment(dB)	15.5±4.2	14.1±3.6	13.7±4.5	13.0±4.5	11.7±4.6	11.0±5.5	11.1±6.5
After treatment(dB)	15.2±4.4	13.6±4.6	12.2±3.9	11.7±3.9	9.9±4.0	9.4±4.9	9.5±6.2
t Value	0.38	0.67	1.85	1.87	2.59	1.97	1.86
P Value	0.705	0.506	0.071	0.068	0.013*	0.055	0.070

*: P < 0.05

Table II - *The comparison of CBCT measurements before and after treatment in both sides.*

Group	Before treatment	After treatment	t Value	P Value
CoC-SHP(cm)	2.43±0.37	2.47±0.38	-2.25	0.029
*CoC-MSP(cm)	5.31±0.31	5.33±0.31	-1.44	0.155
CoC-SCP(cm)	0.91±0.32	0.85±0.33	3.59	0.001**
AIM-SHP(cm)	1.29±0.26	1.29±0.27	0.189	0.851
AIM-MSP(cm)	4.43±0.20	4.43±0.21	0.569	0.572
AIM-SCP(cm)	1.77±0.27	1.74±0.26	4.25	0.000**
cochlea-SHP(cm)	1.45±0.27	1.46±0.26	-0.78	0.442
cochlea-MSP(cm)	3.82±0.23	3.81±0.23	1.06	0.293
cochlea-SCP(cm)	1.63±0.29	1.64±0.28	-0.57	0.571
U-U1(cm)	1.14±0.30	1.19±0.34	-1.86	0.069
M-M1(cm)	1.33±0.42	1.34±0.40	-0.65	0.517
L-L1(cm)	1.59±0.58	1.54±0.58	0.40	0.691

*: P < 0.05
**: P < 0.01

Audiological Tests

The subjects in this study were referred to Beijing Stomatological Hospital where the audiological tests such as pure tone audiometry were performed by otolaryngologist and audiometrician before and after the occlusal splint therapy. The subjects did not wear the occlusal splint during audiological tests.
Pure tone audiometry (Otometrics Conera): Pure tone audiometry was examined in all subjects using a two separate channel audiometer in a soundproof room. In manual audiometry the tone is presented in 5-dB steps in an ascending manner and then increasing in intensity until the threshold is reached. For clinical purposes, air conduction threshold values better than 20 dB HL are considered to be normal.

Statistical Analysis

The data collected in this report were processed to statistical analysis using SPSS (IBM Statistic 23.0). Descriptive analyses contained frequency of variables and central tendency and dispersion measures. The audiological tests and CBCT measurements of the subjects before and after treatment were compared by use of paired t test, independent-samples T test and pearson correlation analysis. The probabilities of less than 0.05 were accepted as significant.

Results

Clinical signs and symptoms: After the treatment, improvement or complete remission of the symptoms was reported by 14 of 16 subjects with myogenous pain, in 8 of 10 subjects with joint pain, in 8 of 12 subjects with joint clicking, in 8 of 11 subjects with tinnitus, in 7 of 9 subjects with otalgia and 4 of 6 subjects with ear fullness. Improvement of headache attributed to TMD after treatment was reported by 2 of 2 subjects, in 3 of 4 subjects with vertigo. In general, subjects with improvement or complete remission in TMD and otological symptoms accounted for 84% and 80% in all subjects respectively.
Audiological tests: In regard to the pure tone audiometry, hearing thresholds were within normal ranges in all the subjects (50 ears), and the air-bone GAP lower than 10 dB (HL) for all frequencies. Before the treatment, there were no differences in PTA between left and right ears. Table I showed the comparison of pure tone air condition thresholds before and after treatment at every frequency in 50 ears. Statistically differences were found in pure tone audiometry thresholds at 2000Hz frequencies before and after treatment.
CBCT: Before the treatment, there were no differences in the measurements of CBCT between left and right sides. Table II showed the comparison of CBCT measurements before and after treatment in both sides. There were statistically differences in the distances between

Table III - *The correlation between PTA and measurements of CBCT before and after treatment.*

Group	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
CoC-SHP	-0.159	-0.053	-0.110	-0.223	-0.019	0.022	0.067
CoC-MSP	0.118	0.155	0.110	0.076	0.007	0.119	0.312*
CoC-SCP	-0.179	0.016	-0.019	-0.080	-0.073	-0.008	-0.368**
AIM-SHP	-0.184	-0.190	-0.122	0.043	-0.114	0.006	0.033
AIM-MSP	-0.172	-0.153	0.064	-0.168	-0.093	-0.032	0.085
AIM-SCP	-0.028	-0.009	-0.001	-0.003	0.119	-0.034	-0.139
cochlea-SHP	-0.095	-0.022	-0.164	-0.142	0.032	0.037	-0.006
cochlea-MSP	-0.066	0.080	-0.094	0.045	-0.173	0.008	-0.063
cochlea-SCP	0.199	0.141	0.090	-0.118	0.068	0.044	-0.201
U-U1	0.000	0.074	0.107	0.112	0.016	0.307*	0.114
M-M1	-0.031	-0.094	0.011	0.135	0.011	0.070	-0.099
L-L1	-0.165	-0.257	-0.200	-0.157	0.091	-0.022	-0.058

*: $P < 0.05$
**: $P < 0.01$

Table IV - *The correlation between the position of CoC and cochlea in sagittal, vertical and coronal directions before and after treatment.*

Group	CoC	cochlea	r Value	P Value
Sagittal direction	0.06±0.12	-0.005±0.06	0.611	0.000**
Vertical direction	-0.04±0.11	-0.010±0.09	0.516	0.000**
Coronal direction	-0.02±0.09	0.012±0.08	0.547	0.000**

*: $P < 0.05$
**: $P < 0.01$

condylar center (CoC) and sella (S)in sagittal and vertical directions (CoC-SCP and CoC-SHP) before and after treatment, and statistically difference between AIM and S in sagittal direction (AIM-SCP). No statistically differences were found in rest of the results.
Correlation analysis: Table III showed the correlation between PTA and measurements of CBCT before and after treatment. The threshold of PTA at 8000Hz were negatively correlated with the sagittal displacement of condyle and positively correlated with the coronal displacement of condyle. The thickness of top 1/3 of anterior wall of tympanum in sagittal were positively correlated with the threshold of PTA at 4000Hz. The positions of CoC were positively correlated with cochlea in sagittal, vertical and coronal directions before and after treatmen (Table IV).

Discussion

Patients with TMD and otological symptoms were given the conservative methods of TMD therapy mainly including occlusal splints, physical therapy and drugs [9,10]. Koskinen J et al treated TMD patients with acrylic removable mandibular bite plates, thermotherapy, muscle relaxants and muscle training, and the treatment of otological symptoms eradicated or reduced 56% in TMD patients [17]. Literature review showed that the average effective rate of TMD therapy (stabilization splint and physiotherapy) for tinnitus symptoms was 69% and 32% unchanged [18]. In our study, the effective rate of tinnitus and otological symptoms were 73% and 80% respectively, higher than the above conservative treatment. Similar to other researches, the treatments of occlusal splints or mandibular orthopedic appliances were reported to be more efficient in reducing the otological symptoms of patients with TMD [17-19]. Therefore, we chose stabilization occlusal splint for TMD treatment in this study, and could make better preparation for subsequent orthodontic treatment. Moreover, the effectiveness of occlusal splints in the treatment of TMD with otological symptoms was confirmed from the clinical perspective, which suggest that patients with TMD may affect the otological symptoms. It should be noted that there was no treatment control group in this study, so our treatment results cannot exclude the placebo effect and natural improvement of the symptoms.
In our study, all subjects accepted audiological tests to understand the auditory functions, so as to further examined the improvement of hearing in TMD patients treated by occlusal splint from the aspect of audiology. Gilles A et al [20] reported that there were no significant differences in audiometric thresholds between tinnitus and control subjects. But Pekkan G [5] found that the pure tone thresholds at frequencies of 125Hz, 250Hz, 500Hz, and 6000Hz showed significant differences between the TMD patients and control subjects. In this experiment, the statistically differences were found in pure tone audiometry thresholds at 4000Hz frequencies before and after treatment. The result was different from that of Sobhy OA et al [21]. The difference in outcome may be related to the different treatment methods and the different inclusion criteria of the enrolled subjects. Although all the enrolled subjects had normal hearing, the hearing thresholds at 2000Hz frequencies improved after occlusal splint treatment which indicated that hearing improved at midfrequency. And hearing thresholds of subjects at all frequencies were reduced after the treatment, we might suggest that the trend of overall hearing improvement in subjects though occlusal splint treatment.
Although the etiological mechanism between TMD and otological symptoms is not clear, but TMJ is adjacent to the anatomy of the middle and inner ear, so the anatomical research were conducted to further confirm the relationship between the TMD and otological symptoms [22,23].
In the present study, AIM and cochlea was selected as a typical structure in the middle and inner ear, and CBCT can better display this bony structure. Our results showed that statistically differences in the distances between CoC and S in sagittal and vertical directions before and after treatment, and statistically difference between AIM and S in sagittal direction. Consistent with other studies [24], the change of the condyle position could be due to the downward and forward displacement after the occlusal splint treatment. The increase of the vertical dimension will cause the changes in the space of TMJ, in order to achieve the goal of reducing the intra-articular pressure and eliminating masticatory muscle dis-

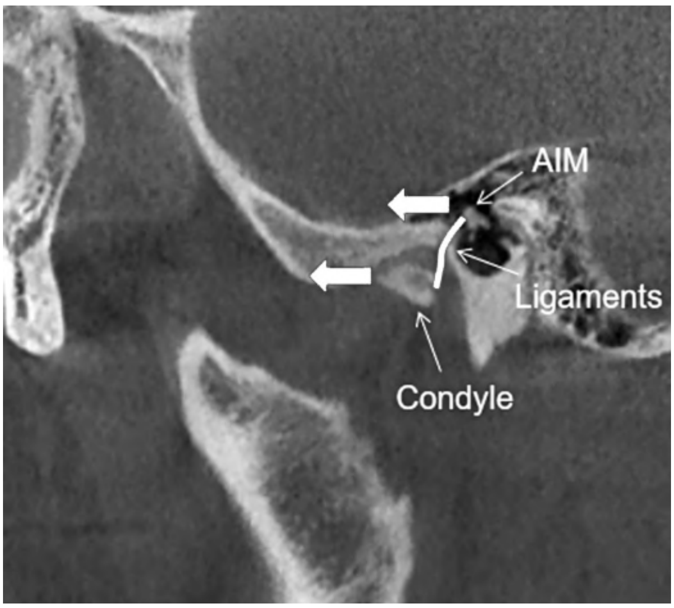

Fig. 2: The displacement direction of AIM and condyle in sagittal directions. The red arrows represented the directions of displacement.

order [25]. Some researches found that discomallear ligament (DML) and/or anterior malleolar ligament (AML) were important to define the limited movement of the malleus [22,23]. The displacement direction of AIM was consistent with condyle in sagittal direction, which may be due to stretching of condyle in conjunction with ligaments between the ossicles and TMJ then affects the development of otological symptoms (Fig. 2).

The positions of CoC were positively correlated with cochlea in sagittal, vertical and coronal directions before and after treatmen. The association between hearing improvement and inner ear structure had not been proven yet. We also found that the threshold of PTA at 8000Hz were negatively correlated with the sagittal displacement of condyle and positively correlated with the coronal displacement of condyle. Whether the displacement of condyle could change the position of middle-inner ear structures which made the improvement of hearing need to be confirmed by further research.

Additionally, the inner posterior portion of the glenoid fossa and the anterior wall of the tympanum are the same bony plates. So, the thickening of top 1/3 of anterior wall of tympanum represents the thickening of the inner posterior portion of the glenoid fossa. The position of the condyle displaced forward after treatment and the posterior joint space were enlarged. The bone tissue of the glenoid fossa was reconstructed because the glenoid fossa was under reduced pressure from the condylar process. Our experimental results showed that after treatment, the condyle process shifted forward and the anterior wall of tympanum/inner posterior portion of the glenoid fossa thickened, which verified the above statement. The anterior wall of the tympanum includes petrotympanic fissure and ligaments that connect TMJ to the middle ear, we hypothesized that the change of the anterior wall of the tympanum might be associated with TMD and otological symptoms, and the reduction of pressure on the middle ear might be one of the reasons for the remission of otological symptoms. In order to understand the relationship between TMD and otological symptoms better, more sample size and studies on stress analysis between TMJ and middle-inner ear need to be further performed.

Conclusion

Improvement of clinical symptoms and hearing thresholds in TMD patients with otological symptoms through occlusal splint therapy suggests that patients with TMD may affect the otological symptoms. The position of the condyle displaced forward and downward after the treatment, and the AIM position changed accordingly. The changes of TMJ position and middle-inner ear structure were correlated with the improvement hearing thresholds. These findings indicate that changes in the TMJ position through occlusal splint therapy might cause the changes in structure of middle-inner ear, which might be one of the reasons for the improvement in otological symptoms.

Riassunto

Indagine riguardanti le modifiche dei test audiologici e le misurazioni della tomografia computerizzata cone beam (CBCT) della struttura dell'articolazione temporomandibolare (ATM) e della strutture dell'orecchio medio interno dopo terapia occlusiva con splint in pazienti con disturbi temporo-mandibolari (TMD) e con sintomi otologici, indagando il meccanismo etiologico tra disturbi temporo-mandibolare e sintomi otologici.

Metodi: sono stati arruolati nello studio 25 soggetti di età compresa tra i 18 e i 40 anni, affetti da disturbi temporo-mandibolari associati a sintomi otologici. Tutti avevano ricevuto un trattamento ortodontico presso l'ambulatorio del dipartimento di ortodonzia del Beijing Stomatological Ospedale.

Tutti i soggetti sono stati sottoposti ai test audiologici di audiometria tonale pura (PTA) e CBCT prima e dopo la terapia con splint occlusale.

Risultati: dopo la terapia con splint occlusale di stabilizzazione, i soggetti con miglioramento o remissione completa dei disturbi temporo-mandibolari e dei sintomi otologici rappresentavano rispettivamente l'84% e l'80% in tutti i soggetti. C'erano differenze statisticamente nelle distanze tra il centro condilare (CoC) e la sella (S) in direzione sagittale e verticale prima e dopo il trattamento e differenze statisticamente tra ATM e S in direzione sagittale. La soglia di PTA a 8000Hz si correlava negativamente con lo spostamento sagittale del condilo e positivamente con lo spostamento coronale del condilo. Lo spessore di 1/3 superiore della parete anteriore del timpano in sagittale si correlava positivamente con la soglia di PTA a 4000Hz.

Conclusione: i cambiamenti nella posizione dell'ATM a seguito di terapia con splint occlusale potrebbero causare i cambiamenti nella struttura dell'orecchio medio interno, che potrebbero essere una delle ragioni del miglioramento dei sintomi otologici.

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