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Measurement of bone conduction characteristics for transmitted vibration sounds of tooth drilling

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Abstract PURPOSE: In this study, we measured the vibration caused during dental treatment by an air turbine handpiece and a micro motor handpiece. We then analyzed the obtained data to develop a method for noise cancellation of such vibration during the treatment of tooth decay. We herein describe the audio characteristics of bone conduction sound made by teeth during dental treatment. We measure vibration sounds of an air turbine handpiece and a micro motor handpiece transmitted from teeth to the middle and/or inner ear and obtain its bone conduction characteristics for reducing uncomfortable dental treatment sounds using active noise control technique in the future. METHODS: First, we measure the frequency characteristics of both acoustic sounds and vibration sounds of two dental handpieces in a special treatment room. Second, we measure the frequency characteristics of bone conduction from teeth to the middle and/or inter ear by actuating a tooth with pure tones of several frequencies in an anechoic chamber. RESULTS: The basic rotational frequency of an air turbine head tip with no-load was about 5,500 Hz. A decline of the rotational frequency was confirmed at the turbine head when the bar came in contact with the tooth, and it was proven that the tooth received the effect of the vibration, when the head made contact with the tooth. The results showed that the micro motor handpiece speed varied from a low of 140 to 210 Hz to a medium speed of 280 Hz and a high speed of 700 to 770 Hz. These results were higher than manufacturer's specifications of micro motor handpiece. The results of the bone conduction amplitude-frequency characteristics were the best audible amplitude-frequency was near 2,000 Hz in the upper and lower left central incisors.

Key words
Air turbine handpiece,
Audition characteristic,
Bone conduction,
Frequency characteristics,
Micro motor handpiece

Introduction

Dental treatment often induces various types of physiological stresses in patients. Factors contributing to these stresses include the clinical environment itself, administration of anesthesia, noise of tooth drilling, tooth extraction and others. There are numerous cases in which a maladjusted behavior is observed, especially in the case of infants who demonstrate anxiety and fear due to such stress[1,2]. Tsuchiya *et al.*[3,4] and Fukuta[5–7] reported on the local anesthesia and instruments for dental treatments that tend to be factors causing a strong emotional reaction in children. The noise of caries removal instruments for dental treatment causes an emotional reaction, which is associated with pain during dental treatment. Such noise can be reduced by use the masking method by using headphones to some extent[8]. However, it is difficult to block out such noise completely because the noise experienced during tooth drilling reaches the middle ear or the internal ear through bone[9,10].

Bone conduction hearing aids are often used to offset hearing loss. Using this same technology

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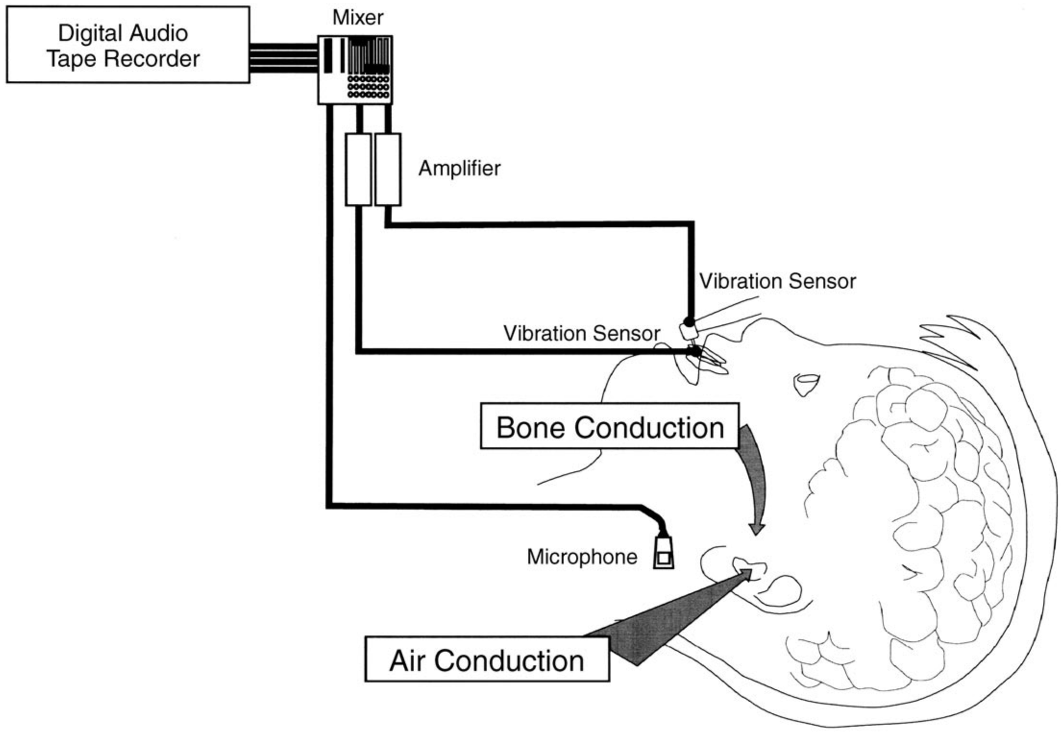

Fig. 1 The hardware composition for the measurement procedure of the vibration sounds of the tooth drilling in experiment 1

in combination with an active anti-noise filter, or so-called noise cancellation technology, we hypothesize that it may be possible to reduce the sound pressure level (SPL: It is an index to show a physical amount of the sound, and the unit is a decibel [dB].) to a greater degree than in traditional systems[11–13]. We thought that a basic research on the bone conduction sound was necessary to design the anti-noise filter.

In this study, we measured the vibrations caused during dental treatment using an air turbine handpiece and a micro motor handpiece. In addition, we determined the audio characteristics of bone conduction sound that was transmitted during tooth drilling.

Experimental Methods and Materials

1. The procedure for measuring drilling vibration in cavity preparation

An adult male with dental caries in his upper left central incisor served as the subject for the study for measurements of air turbine handpiece. He gave his informed consent to participate before the start of the study.

Figure 1 shows a schematic of the various hardware components used in the study. The measurements of dental noise were carried out in the Fukuoka Dental College department of pediatric dentistry attached hospital in a special treatment room which is comparatively quiet than in regular dental clinics. The drill used was an air turbine handpiece (Morita Co., ball bearing, Super ZB PAR-E-O diamond bar, 400,000 to 30,000 rpm).

The measurements of micro motor handpiece were performed that were used for an extracted tooth with dental caries embedded in gypsum. The micro motor handpiece were used by Morita Co., TR-5 Acompact direct current motor (2,000 to 40,000 $\pm$ 2,000 rpm). The Morita micro motor system that uses it by the actual experiment can control the speed of three stages. Then, the measurement was measured at the speed of three stages in consideration of the situation in clinical.

The measurements of drilling of proximal dental caries vibration in cavity preparation were recorded with a vibration pickup device attached to it (ONO SOKII Co., microphone NP-2113) on upper central incisor. Signals were recorded using an 8-channel digital recorder (AMCRON Co., GLM-100) while

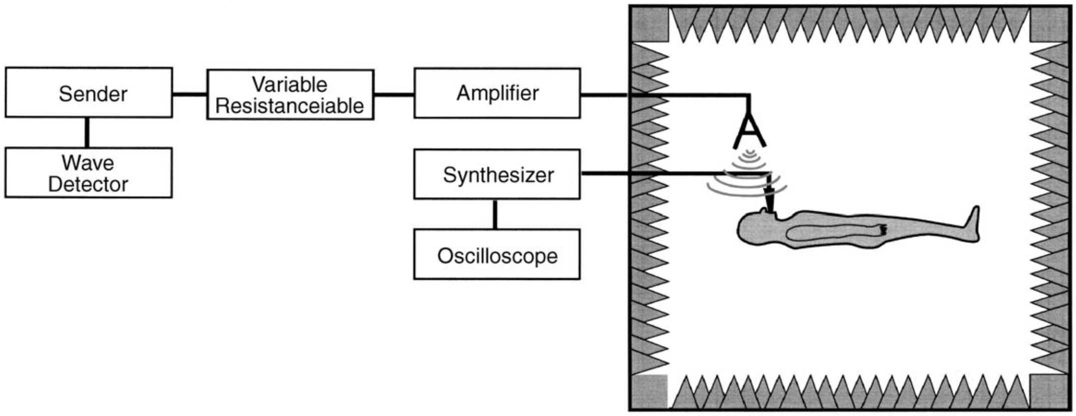

Fig. 2 The hardware composition for measurement of the bone conduction amplitude-frequency characteristics in experiment 2

the drilling was carried out. All measured data were digitized and their frequency characteristics were calculated by discrete Fourier transform with 32 kHz sampling frequency, 16 bits quantization levels, and 512-point (16 msec) Hamming window.

2. The procedures for measuring the bone conduction amplitude-frequency characteristics

The experimental scheme and equipment used are shown in Fig. 2. The bone conduction amplitude-frequency characteristics were measured in an anechoic room at Kyushu University.

An actuator was fixed to a tooth simulated the bone conduction sound which was generated by dental noise during cavity preparation (Fig. 3). The actuator is fixed to a tooth with a metal bar so that it did not interfere with the tooth or lip for preventing experimental accident (electric shock etc.). The actuator was driven by a rectangular wave voltage and showed 3.3 V, 6.5 V, and 3.2 V of a peak, a maximum, and minimum voltages, respectively. The vibration frequency was classified by 8 kHz octave bands at 62.5 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, and 2 kHz in the upper and lower left central incisors. However, the bone conduction amplitude-frequency characteristics from a tooth to the middle ear and auris interna were estimated from the air conduction sound which was moved by a sound volume equal to the bone conduction sound, because the direct measurement of the auris interna was impossible. Specifically, the SPL was adjusted in comparison to the bone conduction sound from the tooth by the actuator and the air conduction sound emitted from a loudspeaker hung from the ceiling of the anechoic camber. Acoustic SPL was adjusted by 2 dB steps to obtain same vibration SPL. The characteristics of air conduction sound that was equivalent to the bone conduction characteristics with different vibration frequencies were obtained, and the loudspeaker SPL near the external ear was measured by a noise meter. This process was repeated

Fig. 3 Experimental set up for measurement of bone conduction

The actuator was fixed on a tooth and simulates of the vibration sounds.

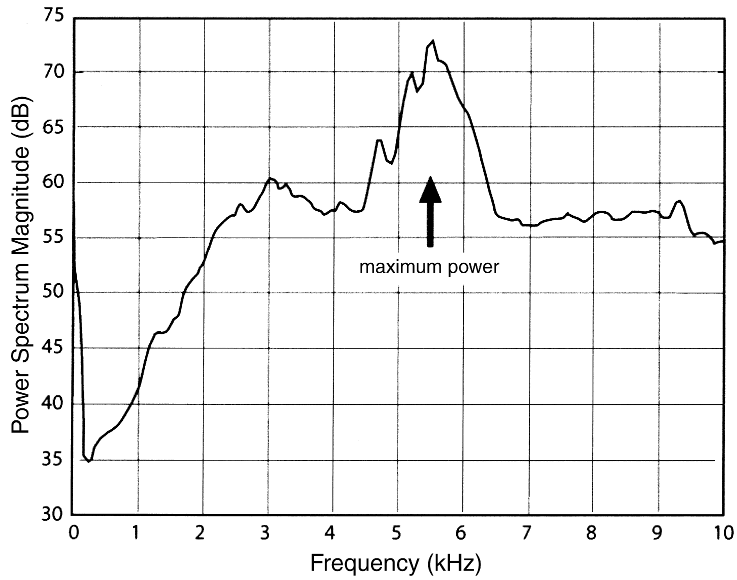

Fig. 4 The result of the measurement of power spectrum that was vibration sound of the air turbine handpiece

The highest sound pressure level is admitted by about 5.5 kHz (see arrow).

by changing both frequencies of the actuator and the SPL of the loudspeaker. As a result, the average values were determined three times in order to avoid any errors.

Results

1. Results of the drilling noise measurements in cavity preparation

1) Air turbine handpiece

The rotational frequency of a turbine head tip without touching any teeth was about 5.5 kHz and decrease from 5 kHz to 4 kHz when it touches a tooth for drilling (Fig. 4). These findings showed that the tooth received the effect of the vibration when the drill came in contact with the tooth (Fig. 5). In addition, the measured value of the upper left central incisor in the treatment region was equal to the rotational frequency of the turbine head.

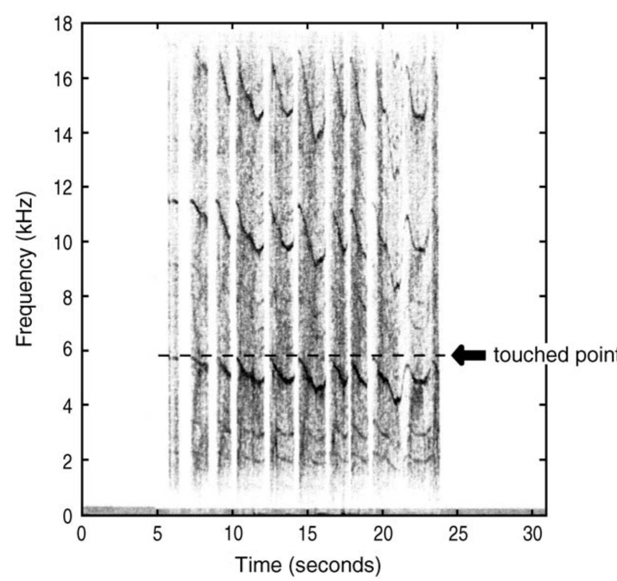

Fig. 5 The result of the measurement of tooth vibration when a turbine head tip was touched to tooth

2) Micro motor handpiece

We next measured the rotational frequency of a micro motor used for an extracted tooth embedded in gypsum with three different levels (low, medium, high) (Fig. 6). According to specifications in a user manual, the basic turn speed of the micro motor handpiece at a low, middle, and high speed ranges are about 2,000–3,000 rpm (33 to 50 Hz), 2,000–9,000 rpm (33 to 150 Hz), and 2,000–40,000 rpm (33 to 667 Hz), respectively. Our measurement of the rotational frequency of the three levels was about 700–770 Hz, which was higher than manufacturer's specifications. A high frequency, as high as almost 5 kHz was also observed.

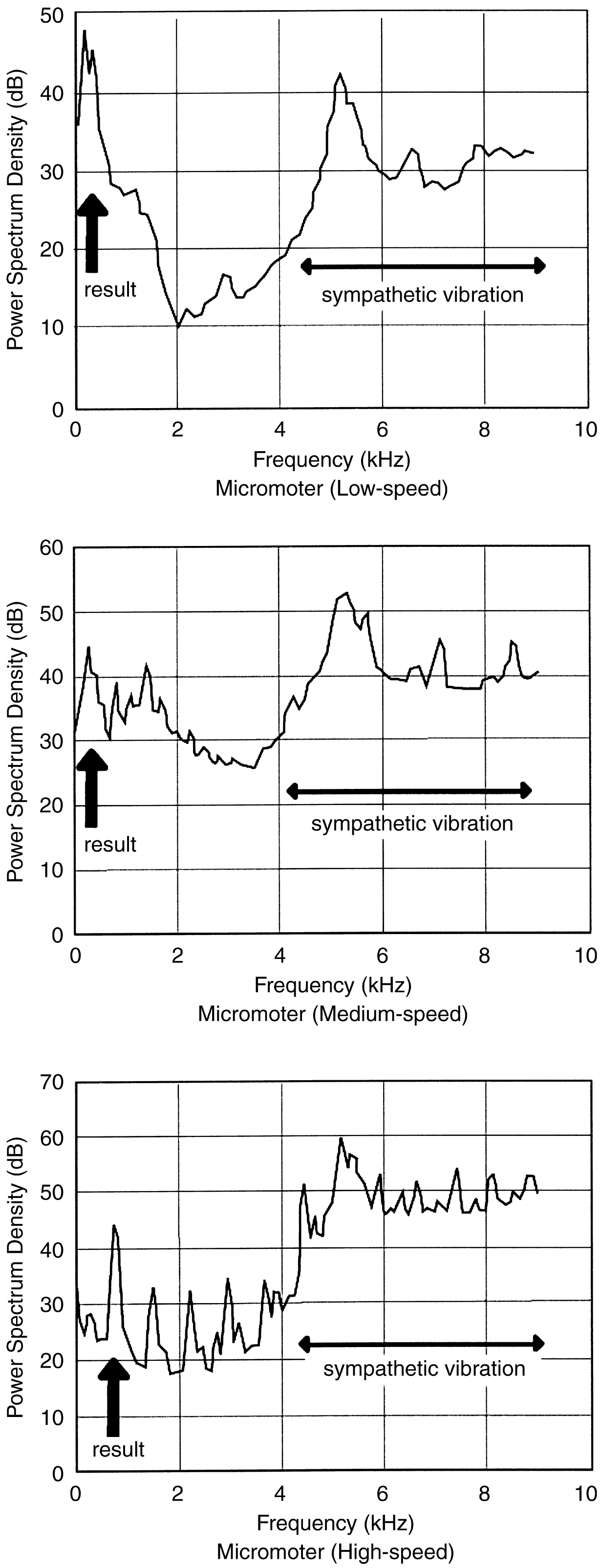

Fig. 6 The results of the measurement of teeth vibration when a micro motor head tip was touched with three different speeds

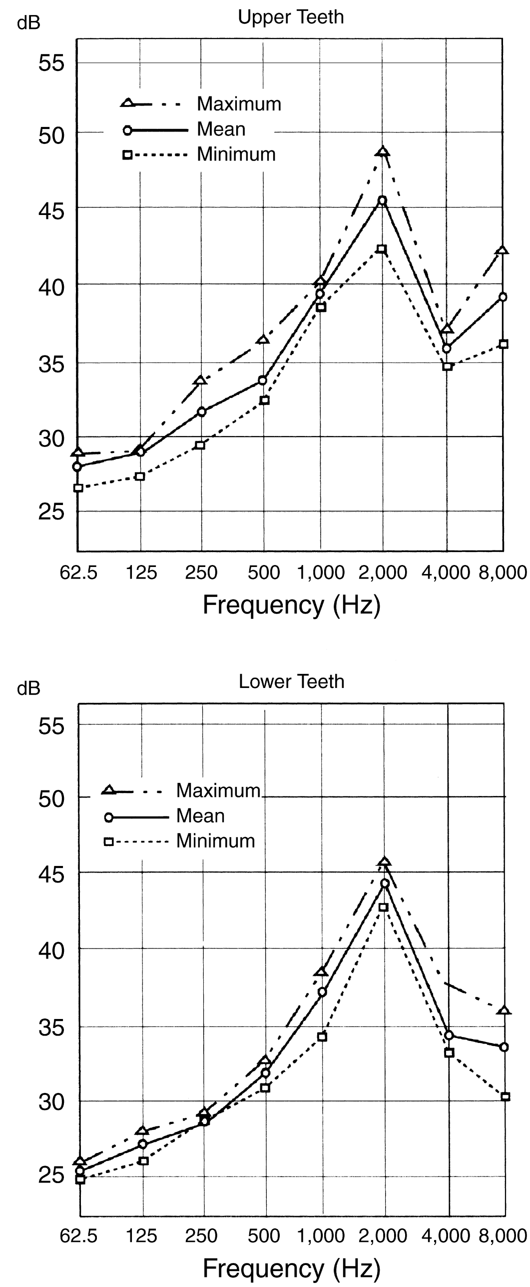

Fig. 7 The results of the measurement of audition characteristic when given the vibration sounds to teeth with octave band

2. Findings for bone conduction amplitude-frequency characteristics

Sound emitted from a loudspeaker in the ceiling used sinusoidal and rectangular acoustic waves. The frequency response to the vibrations in the maxilla left side central incisor, and the results of the vibrations in the lower jaw left side central incisor are shown in Fig. 7. Approximately 2,000 Hz also

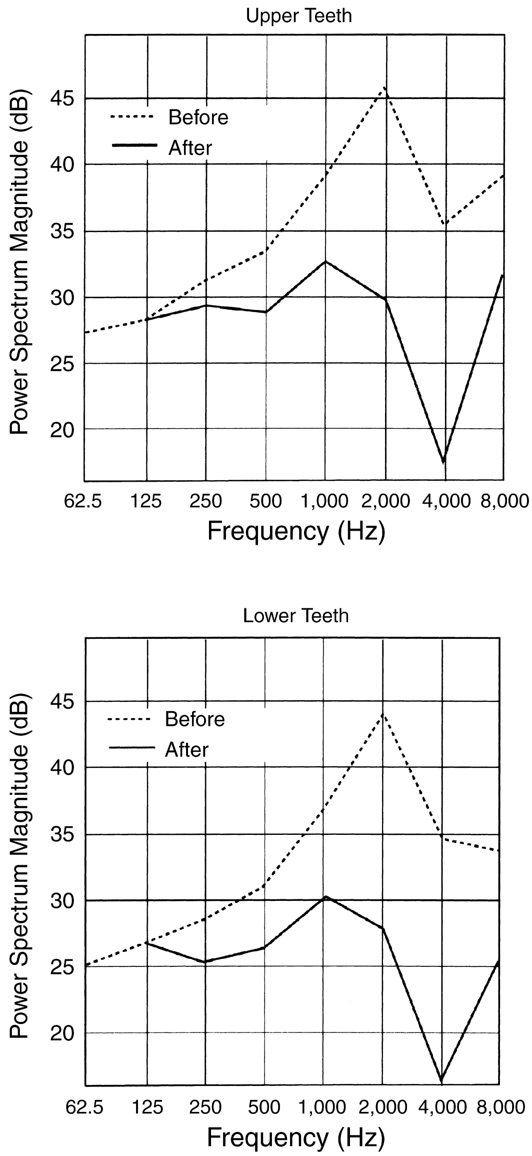

Fig. 8 The loudness characteristics in which influence of the external ear and tympanic membrane were excluded

seemed to be the most highly audible level on the upper and lower left side central incisors. However, this finding may be largely affected by the loudness characteristics of the external ear.

Figure 8 showed the amends result based on a loud characteristic of the external ear.

Discussion

The main type of dental treatment in ancient times was extracting teeth[14]. Tooth drilling instruments were developed in the 19th century, and electric drilling instruments and air turbine drilling handpieces were developed afterwards. However, such air turbine drills and micro motor handpieces, which are current mainstream cutting devices generate loud noise, and patients feel a high degree of vibration during treatment. It makes patients feel a high level of fear or anxiety during dental treatment.

Tsuchiya *et al.*[4] used a polygraph to observe a child's body motion during dental treatment in order to examine the emotional reaction of the child during dental treatment. His study showed that a micro motor handpiece and an air turbine handpiece could cause a "false operation stimulation", "tactile sense stimulation", "ocular-irritation" and "auditory stimulation". The micro motor handpiece thus caused emotional reactions related to "ocular-irritation", "tactile sense stimulation", "auditory stimulation", "false operation stimulation", and emotional reactions in the air turbine resulted from "tactile sense stimulation", "ocular-irritation", "auditory stimulation" and "false operation stimulation", which were strongly related to the inside action. These results were due to the stress of the infant patient caused by auditory stimulation of contact vibration which is generated by a drill touching the tooth directly. As a result, the infant patient seemed to feel stronger stress to the contact vibration generated by touching a tooth than the drilling noise.

In our daily life, we primarily hear sounds through air conduction. However, when vibrations are applied directly to bone, we are able to hear solid vibration sounds. Such bone conduction sound does not use the tympanic membrane but is transmitted to the middle ear and auris interna directly. Based on this phenomenon, bone conduction hearing aids have been developed for hearing impaired patients with a failure of the external and/or middle ear[8]. Patients hear two types of noise during dental treatment. The first type is conducted through the air and reaches the auditory sense through the external ear. The second comes through bone conduction and reaches the auditory sense using the alveolar bone and jaw bone from the tooth. The patient's awareness of air conduction sounds may be decreased by listening to music, or covering ears[3,12]. However, the auditory sense characteristics of bone conduction remain to be studied in depth. Regarding bone conduction, we know decreasing or cancelling the SPL can be achieved using an active filter (anti-noise device) which for sound conduction hearing impaired as bone conduction hearing aid and noise cancellation technology[11–13]. The dental engine frequently used for dental care and way's to reduce the drilling vibration of an air turbine handpiece, and the auditory sense characteristics of bone conduction sound were all investigated in order to obtain basic data which could help in eventually designing an active sound filter.

1. Drilling vibration of a tooth

We measure vibrations induced in a tooth by an air turbine handpiece and a micro motor handpiece used for dental treatment. According to the specifications of the manufacturer, the air turbine handpiece produced a 400,000 ± 30,000 rpm rotational frequency, so a very high vibration was thus anticipated. However, the fundamental frequency was about 5.5 kHz as measured with a vibration meter installed on the side of the air turbine handpiece, and we found that the frequency varied during caries removal between 5 kHz to 4 kHz. With the pickup installed directly on the tooth that was being drilled, the frequency was found to be similar to that of the head section of the air turbine handpiece. In addition, the vibration decreased after installing a pickup in the lower left central incisor during removal of decay in the maxilla left side central incisor. No further measurements were performed. When treating the tooth in the lower jaw, a decrease in the high SPL was observed, since the temporomandibular joint and soft tissue served to buffer the vibration somewhat. The frequency was measured for an micro motor handpiece, and it was found to range from 33 Hz to 770 Hz. Humans can distinguish sounds ranging in frequency from 20 Hz to 20 kHz. However, according to a loudness curve, human hearing is most sensitive in a range from several hundred to several thousand Hz. Sound becomes less audible when the frequency is low or high, even when the SPL is the same. As a result, the vibrations from an air turbine handpiece and a micro motor handpiece appear to be highly audible as bone conduction sound.

2. Bone conduction amplitude-frequency characteristics

Solids propagate sounds at higher velocity than does air. For example, though the sound velocity in air at a normal temperature and normal pressure is 343 m/s, it reaches 1,500 m/s in sea water and 3,400 m/s in concrete. However, there is no consensus as to the sound velocity in bone. The sound velocity of bone conduction sound seems to range from 2,000 to 3,000 m/s, based on the composition of the bone. In addition, bone seems to have frequency characteristics unlike usual aerial conduction sound, since bone is porous and has a complicated structure. However, it is not possible to measure the frequency characteristics of the direct auris interna by producing bone conduction sound. As a result, the authors simulated the frequency characteristics of bone conduction sound, which is transmitted from the tooth, and compared the findings with the vibration of the specific frequency used by an actuator installed on the tooth in order to determine whether the air conduction sound of equal frequencies is audible for various SPLs. The results are shown in Fig. 7.

Bone conduction sound, which directly affects the middle ear and auris interna, was also compared with air conduction sound caught through the external ear and tympanic membrane. Compensation based on the loudness characteristics of the external ear were clarified out by Shaw's report[15]. As a result, we tried to determine the correction value shown in Fig. 8. According to the findings of this study, it was possible to collect sufficient basic data to produce an active filter. In the future, further studies on the development of an active filter will be carried out based on the data obtained in this study.

Acknowledgments

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