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APPLICATION OF VIBROACOUSTIC DIAGNOSIS IN ASSESSING BRIDGES CONNECTING TEETH AND IMPLANTS TO TREAT TOOTH ABSENCE IN SEA VESSEL CREWS

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ABSTRACT

Implant treatment is a proven method in dentistry for partial and complete missing teeth reconstruction. In some clinical situations it is advisable to limit the number of implants, which can be obtained by making a bridge connecting the patient's own tooth with the implant. So far, the possibility of using safe and permanent connections of natural teeth with implants has been examined to a small extent due to the dangers resulting from the different mobility of dental implants and teeth.

An attempt was made to use vibro-acoustic techniques to evaluate various combinations of teeth and implants. Pilot studies were carried out on cadavers-pig mandibles with implants. There were recorded sounds in the immediate vicinity of the mandible formed in response to impulse excitations carried out with a point hit against a tooth or implant before and after their joining with a bridge. The comparison of spectra allows to see features indicating a high probability of being able to distinguish between the examined configurations.

The results of the research should contribute to a better understanding of the mutual relations between the dental implant and the tooth, which are included in bridge. In the perspective, it will enable to assess the level of safety and to identify clinical situations that allow to obtain dental bridges based on teeth and implants.

Keywords: implant and tooth connection-dental implant-bridges-vibroacoustic diagnosis-FPD

INTRODUCTION

The most dangerous disease in the history of shipping, and one which claimed the lives of thousands of seamen, was scurvy [2,3]. This is a multi-organ disease, the cause of which is a deficit of ascorbic acid, which is required for the synthesis of collagen and maturity in an organism [2,3,9]. It results in idiopathic hemorrhage, gingivitis and periodontosis, with subsequent hypertrophy. The teeth become more mobile, and, as a result, fall out. In modern times, cases of scurvy are no longer recorded among seamen and sailors, and the loss of teeth at sea is nearly always the result of injuries, accidents or impacts, or alternatively a lack of stomatological care. Injuries in the region of the facial skeleton on board a boat that are accompanied by the loss of teeth most frequently affect several teeth in the region of the aesthetic zone, and may also affect the alveolar bone of the jaw or the alveolar part of the mandible. If it is impossible to reconstruct the teeth affected by the injury, and we are forced to remove them due to the conditions that are prevalent at sea and on vessels, the lost teeth ought to be replaced with permanent prostheses rather than mobile ones. One method of reconstructing missing teeth which has proven its usefulness is implant treatment [18,19,20].

Bridges supported by implants are highly effective in terms of transferring chewing forces, and also provide high levels of acceptability and satisfaction [22]. For implantation to be successful, appropriate bone volume and quality are required where a tooth is missing. In order to achieve complete stomatological rehabilitation, it is sometimes necessary to place several implants, and if the anatomical state of the bones is insufficient, to perform additional procedures in order to condition the bone stock [1,21]. These procedures are frequently traumatic and painful, and extend the time required to achieve complete stomatological rehabilitation. In order to avoid this and to limit the number of implants used, and also to reduce the time and costs connected with treatment without being forced to use mobile prostheses, it is possible in some clinical situations to create a bridge connecting the patient's own tooth with an implant [4,15,16]. Hitherto, the possibility of using safe and durable connections between natural teeth and implants has been researched only to a limited degree, due to the dangers resulting from the different mobilities of stomatological implants and teeth. As part of our research into the quality and durability of such connections, we use the vibroacoustic diagnosis technique, which can be broadly applied for the purpose of assessing the state of technical objects [5,6,7,11,12,13,14]. An attempt was made to use a vibroacoustic signal to assess the state of stomatological bridges connecting tooth and implants.

In the course of clinical research into implants and teeth, diagnosis is commonly made with the use of the percussion method. Information is obtained not only from the reaction of a patient, but also from the kind of sound produced. An implant that is integrated with a bone or a tooth in ankylosis produce evidently different percussion sounds than a healthy ones or those affected by changes. As a result of this impact, sound carries a great deal of information that is useful in terms of diagnosis, and its interpretation may make it possible to obtain more detailed information on the actual state of a bridge and its constituents in places that are invisible to clinical and radiological research.

EXPERIMENTAL DETAILS

To verify our hypothesis of the possibility of applying the information obtained from a sound signal generated by an impulse impact onto a tooth or implant for the purpose of assessing bridges connecting teeth and implants, we conducted this research using pig mandibles. Due to the density, hardness and morphology of the bones, the properties of these mandibles resemble those of the human alveolar part of the mandible. The tradition of using these animals in anatomical research dates back to the beginning of the current era; as early as the second century, Claudius Galenus described human anatomy based on the use of the anatomy of pigs. The similarity between the human and pig organisms has also attracted attention from contemporary researchers [8,17].

Nowadays, stomatological wards tend to use titanium implants (with a typical length of between 10 to 16 mm and diameter between 3.2 and 5 mm), in conjunction with prosthetic connections (diameter 3.75 mm) that can extend an implant by 7 mm. These elements were treated as a vibrating system, and the dynamic model were adopted as the basis for estimating a range of frequencies for choosing signal recording and analyzing equipment in the course of vibroacoustic research.

In the general case, the dynamic model has the form of a matrix equation:

$$\mathbf{M}\ddot{x}+\mathbf{C}\dot{x}+\mathbf{K}x=\mathbf{P}(t) \tag{1}$$

In Eq. (1), $\boldsymbol{x}$ is a generalized coordinate; $\mathbf{M}$ is the mass matrix; $\mathbf{C}$ is the damping matrix; $\mathbf{K}$ is the rigidity matrix; and $\mathbf{P}(\boldsymbol{t})$ is an extraction vector.

For practical reasons, we assume that a model consisting of a bent beam with a concentrated mass is sufficient for a qualitative analysis of the vibration of the system. Fig. 1 shows the layout of the beam and the system of coordinates adopted, and illustrates the bending of the modeled structure. The simplest description of bending vibration may be reduced to the equation of motion with a single degree of freedom, neglecting damping. It was additionally presumed that flat cross-sections remain flat after deformation, and also that strains along the beam axis are negligible [10].

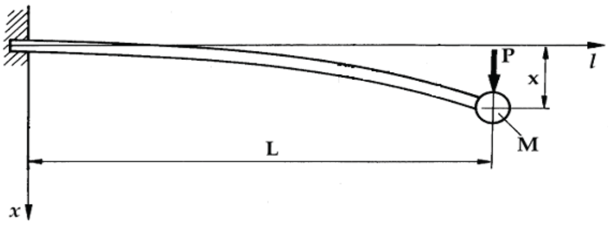

Fig. 1. Model of a vibrating beam with a concentrated mass

Based on these assumptions, the total energy of system shown in Fig. 1 at any given moment consists of the potential energy of elasticity and the kinetic energy of the concentrated mass $\boldsymbol{M}$. We can assume that the elastic energy of the beam at location $\boldsymbol{x}$ is equal to the work required to bend the free end by $\boldsymbol{x}$. If $\boldsymbol{P}$ is a static force keeping the system in equilibrium, the energy is expressed by the following equation:

$$V=\frac{Px}{2} \tag{2}$$

For the beam in Fig. 1, a deflection arrow depends on the applied force in the following way:

$$x=\frac{PL^3}{3EI} \tag{3}$$

In Eq. (3), $\boldsymbol{E}$ is the Young's modulus of the beam material, and $\boldsymbol{I}$ is the moment of inertia of a cross-section in relation to the neutral axis. After transformation to the following form:

$$P=\frac{3E}{L^3}x \tag{4}$$

and substituting Eq. (2), we obtain a description of the elasticity potential energy as a function of the bending of the beam end:

$$V = \frac{3E}{2L^3}x^2 \tag{5}$$

The kinetic energy of the concentrated mass located at the free end is:

$$E_k = \frac{Mv^2}{2} = \frac{1}{2}M\left(\frac{dx}{dt}\right)^2 \tag{6}$$

Since we ignore the influence of damping in this model, the total energy of the considered structure does not vary, and consists of the kinetic energy of an implant, which is treated as a particle, and the elastic potential energy:

$$E_c = \frac{1}{2}M\left(\frac{dx}{dt}\right)^2 + \frac{3EI}{2L^3}x^2 = const \tag{7}$$

Differentiating with respect to time and dividing by ***dx/dt*** results in the equation of motion in the following form:

$$M\frac{d^2x}{dt^2} + \frac{3EI}{L^3}x = 0 \tag{8}$$

The mechanical system described by this equation undergoes harmonic vibration at the following frequency:

$$f = \frac{1}{2\pi}\sqrt{\frac{3EI}{ML^3}} \tag{9}$$

The abovementioned form of equation in Eq. (9) makes it possible to estimate the resonance frequency of the beam in terms of the concentrated mass, type of material, shape of the cross-section, and the length. Using this model (and taking into consideration the properties of titanium, such as its density ρ=4507 kg/m^3 and Young's modulus E=1.16·10^5 MPa, and the moment of inertia of a round section), the natural frequencies for the two implants are 38.436 kHz and 52.538 kHz, respectively. The simplifying assumptions adopted here, and the divergence between the theoretical description and reality (primarily due to the influence of rigidity from mounting an implant and the damping in the system), mean that this solution provides only a qualitative insight into the actual fundamental frequency of vibration of the implant-jaw structure, and the frequencies of the vibrations will be lower than expected on the basis of these calculations. Nevertheless, recording and analyses ought to be performed with the use of the set of measurement devices, making it possible to process vibroacoustic signals in a range of frequencies no lower than the estimated natural frequencies.

EXPERIMENTAL METHOD

Due to the possibility of obtaining frequency results exceeding the acoustic band, a measuring path was configured that consisted of a GRAS 40BE capacity microphone and an ICP GRAS 26CB pre-amplifier, together with a multi-analyzer (PULSE Bruel & Kjaer), using a 3052-A-030 module. This set-up made it possible to conduct measurements and analyses in real time of constituent frequencies of up to 100 kHz.

The vibroacoustic experiments were performed inside an anechoic chamber. The mandible was stabilized in a vice, and a metal shaft impulse impact was used to hit certain points of the teeth. The microphone was located in the direct vicinity of the jaw. The elements of the system are shown in Fig. 2).

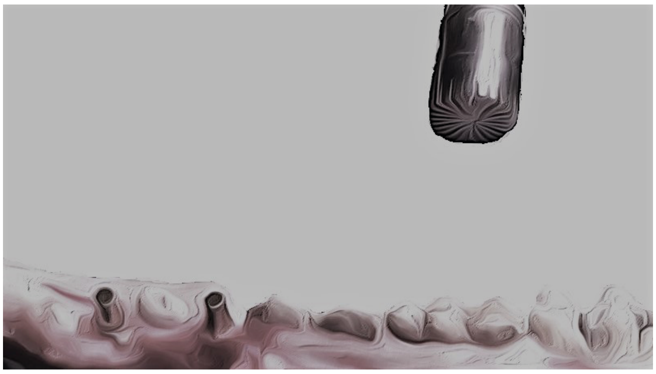

Fig. 2. The researched object

For the experiments, randomly chosen fresh pig mandibles (extracted from the temporomandibular joint) with teeth in a similar condition were used; these were obtained from an abbatoir after slaughter for the purposes of consumption. The procedure of inserting the implants was performed in a room where the temperature was 19–21°C. In the physiologically toothless part of the pig mandible, the mucoperiosteal flap was cut and detached with the use of a lancet, raspator, and surgical tweezers. The location of the planned implantation was marked with the use of a rosette drill. Preparing a site for an implant was performed in accordance with the sequence recommended by the manufacturer of the implants.

Three drills with increasing diameter were used; the fourth one, a preparatory drill, was calibrated with the inserted implant in mind. The SGS implants (Swiss Implant Systems) were screwed into the prepared location (with moment 0.35–0.40 Nm), and a prosthetic connection was fixed on the mounted implant with the use of screws. Implants 1 and 2 were elements with diameter 5 mm and length 17 mm, while Implant 3 had a diameter of 3.2 mm and a length of 10 mm. The bridge was made of hard acryl (Pattern-Resin LS), which was prepared and used in accordance with the recommendations of the manufacturer.

This research included a real-time spectral analysis of the sound signals generated as a result of hitting the implant or tooth with the shaft of a stomatological tool. The spectra were calculated based on the Fourier transform of the short time periods observed in the course of a particular acoustic phenomenon. Recording and analyzing the signal was initiated by an impact, and to eliminate accidental disturbances, 10 temporary spectra established on the basis of time periods after hitting the same point repeatedly were averaged.

The collected research data, can be used to search for vibroacoustic measures that reflect the stability of mounting permanent stomatological prostheses in a patient's jaw and the state of bridges connecting teeth with implants. The resulting database and medical expertise can provide real evidence for the usefulness of sound signals in terms of broadly understood stomatological diagnoses.

RESULTS

The following figures show several averaged spectra of sound signals, representing two natural teeth, three implants, and teeth connected with implants by means of a bridge. From an initial comparison of these frequencies, we can observe features that are typical of a particular case. It should be noted that in the spectra representing sounds generated after the impact extractions of the teeth (Figs. 3 and 4) in a range above 20 kHz, several equidistant peaks can be seen, whereas it is difficult to see any such features in Figs. 5, 6 and 7, where the sounds were generated by means of a point impact on an implant. The varied nature of the frequency spectrum is connected with the lower rigidity of mounting of natural teeth in comparison with implants, and the resulting higher values of the frequency vibration, which is particularly noticeable in the case of Implant 3 (Fig. 7).

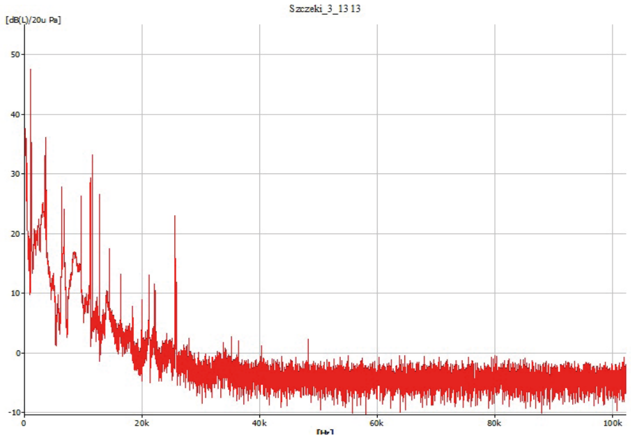

Fig. 3. Spectrum of an acoustic signal after the impulse excitation of Tooth 1

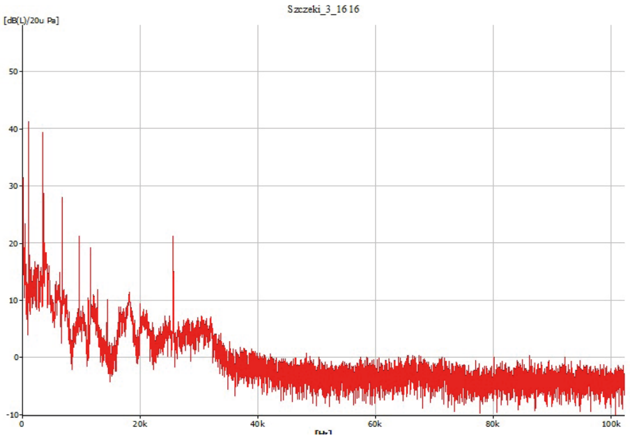

Fig. 4. Spectrum of the acoustic signal after the impulse excitation of Tooth 2

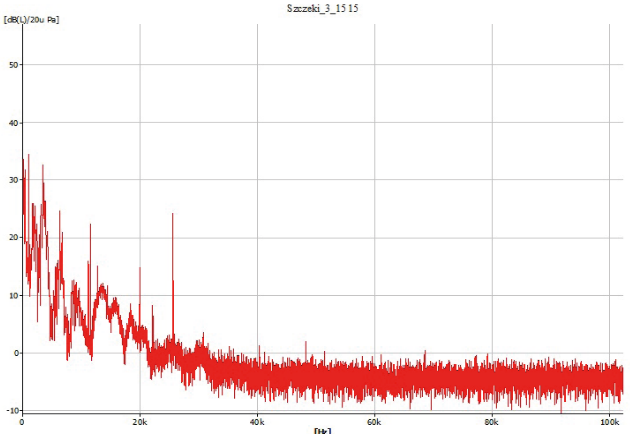

Fig. 5. Spectrum of the acoustic signal after the impulse excitation of Implant 1

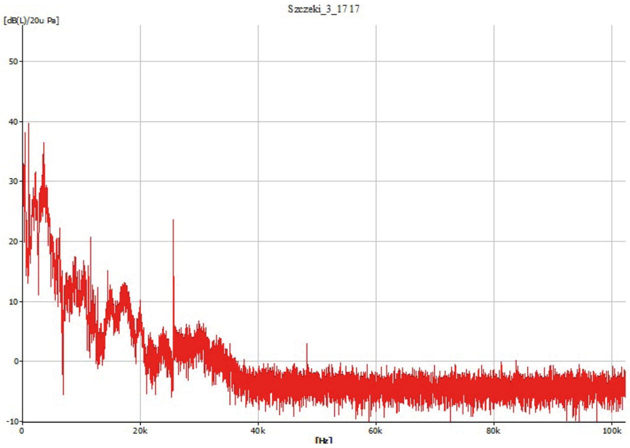

Fig. 6. Spectrum of the acoustic signal after the impulse excitation of Implant 2

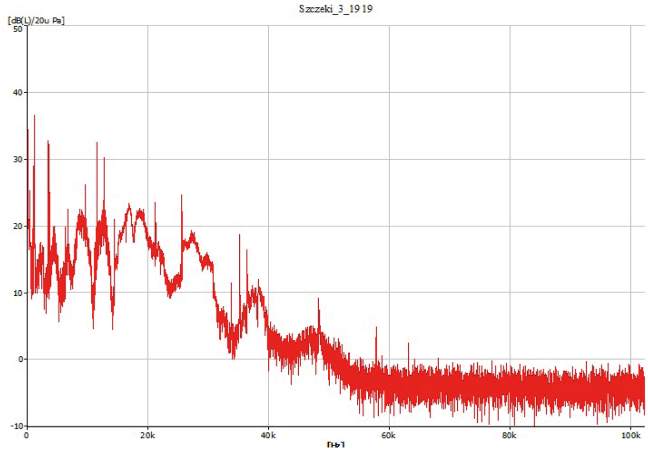

Fig. 7. Spectrum of the acoustic signal after the impulse excitation of Implant 3

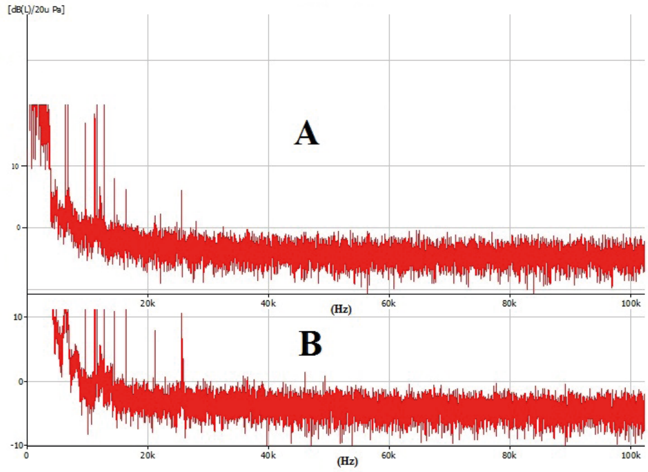

Fig. 8.
A: Spectrum of the acoustic signal after impulse excitation in the vicinity of Tooth 1, connected with Implant 1
B: Spectrum of the acoustic signal after impulse excitation in the vicinity of Implant 1, connected with Tooth 1

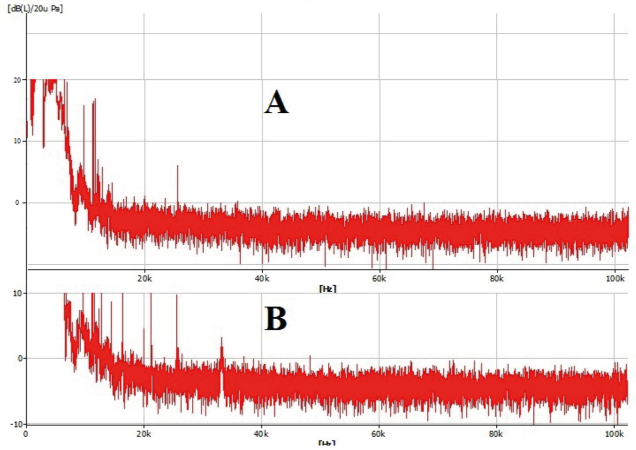

Fig. 9.
A: Spectrum of the acoustic signal after impulse excitation in the vicinity of Tooth 2, connected with Implant 2
B: Spectrum of the acoustic signal after impulse excitation in the vicinity of Implant 2, connected with Tooth 2

Very similar forms of spectra are obtained from signals after impacting the bridges connected with teeth and implants, regardless of the stimulation point. This is superbly illustrated by the pairs of charts in Figs. 8A and B, and 9A and B. The forms of these graphs are clearly different from those representing single teeth or implants, and this reflects a change in the dynamic properties after connecting them by means of a prosthetic construction.

This qualitative assessment of the obtained spectra makes it possible to observe features indicating a high likelihood of of distinguishing the examined elementary cases by means of vibroacoustic diagnostics. On the basis of estimations of the natural frequencies of vibration of implants and teeth it was possible to connect the shapes of these spectra with the dynamic structures of the systems composed of teeth mounted in the mandible together with prosthetic constructions.

CONCLUSION

- The results of the research conducted here demonstrate the accuracy of our innovative conception of the use of sounds generated by percussion diagnosis for the purpose of assessing bridges connecting teeth and implants. Through combining the experience of doctors and engineers, we can provide a basis for broadening and enriching medical diagnosis by using the information contained in a sound signal, which has hitherto been used only to a minor extent.
- The results of this research are expected to contribute to improving the knowledge of the relationship between a ental implant and a tooth forming one dental prosthesis. In the future, it will make it possible to assess the safety of these prostheses and, more broadly, to identify clinical situations that make it possible to apply permanent prostheses based on teeth and implants. Combining implants with teeth is expected to reduce the time needed to treat a patient, and diagnosis via the use of vibroacoustic methods will make it possible to assess the quality of these bridges.
- Even at this initial stage of research, there are also real grounds to hypothesize that further analyses may contribute to development of advanced tools supporting stomatologists in the process of diagnosing teeth and permanent tooth prostheses, which will consequently give qualitative improvements in the process of treating tooth absence in case of sea vessel crews.

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