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Tooth Mobility Measurement of Dental Implants

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SYNOPSIS

The use of dental implants has increased together with increases in the human life span and it has become an imperative subject for dentists to familiarize themselves with this treatment modality. Unfortunately, there has been no practical and quantitative method for in vivo evaluation of the stability of dental implants. In the tooth mobility examination, the tactile sense of natural teeth is different from that of dental implants. The authors have developed an automatic diagnosis system of tooth mobility for clinical use. The biomechanical mobility of peri-implantium is measured with a pseudo-random vibration, from which the viscoelasticity c_1, c_2, k of peri-implantium is obtained. The diagnosis system has been applied to the quantitative evaluation of the stability of implants : endodontics endosseous implants (titanium pin), endosseous implants (Bioceram). It has also been applied to the evaluation of the long-term prognoses of dental implantation (Bioceram) and the examination of intramobile implant (IMZ), and the satisfactory results have been obtained.

1. INTRODUCTION

When we lose a function and form of a part of living body due to injury or disease, we make up for the local defect in function and form by two methods : (1) transplantology using living tissues

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and organs (2) implantology using artificial materials such as plastics, metals and ceramics [1]. As we enter the aging society, the public has high expectations for dental implants which can take the place of and function just like natural teeth. In order to evaluate a dental implantation, the observations of support system of implants placed in experimental animals are made physiologically and anatomically through a scanning electron microscope [2]. Although the materials and configurations of the implants are important, a biomechanical research of the implants is also indispensable [3]. An acoustic tapping method (10 to 150 kHz) was proposed for assessing the inter-facial rigidity of various bone implants [4]. There has also been much work using the finite element method (FEM) [5] on the stress analysis of the tissues surrounding the implant. However, there has not yet been any reports of diagnostic methods for the clinical evaluation of dental implants. The evaluation of the implant whether it has succeeded or failed has been a subjective one by each dentist. A practical, clinical method for the evaluation of dental implants is needed.

Although the mobility test by palpation is the simplest and most basic clinical method, it is difficult to evaluate the implant with the same tactile sense used to examine natural tooth. Siemens of Germany now markets a simple instrument, the Periotest, for the objective measurement of periodontal function [6]. This system has several weak points in diagnosing tooth mobility [7]. In particular, the impact force may damage the implant, the surrounding tissue or the prosthetic restoration on the implant. Because the evaluation of mobility of healthy or periodontally involved natural teeth has been subjective, we developed a diagnosis system for teeth mobility [7,8], and have applied it clinically [9]. We have also applied this apparatus to the evaluation of different implants and new implant materials.

2. MEASUREMENT OF BIOMECHANICAL PROPERTIES

The most common and simplest testing of biomechanical properties would be a manual tooth mobility examination with an instrument or forefinger. The mobility is grouped into 4 degrees (M0-M3). A periodontium diagnosed as M0 is clinically firm, healthy and within normal physiological mobility. The higher number indicates both buccolingual and apical movement [10]. The classification by the manual examination involves a subjective estimation based on experiences. The shock-absorbing system of natural teeth depends on gingiva and periodontal membrane surrounding the teeth. The manual examination of natural teeth is considered primarily to estimate a viscoelasticity of periodontium including the periodontal membrane. The periodontal membrane of natural teeth, which is 0.1-0.3 mm in width, is fibrous connective tissue composed primarily of collagen fibers, perfused by a rich network of peripheral blood vessels. The primary function of the periodontal membrane is support of the tooth in the alveolar bone [11]. Together with the gingiva, it moderates the impact force on the teeth. The biomechanical characteristics of the implant, which must support the forces of occlusion and mastication, is extremely important in planning the prosthetic restoration, including the implant itself. On the other hand, a load-displacement characteristic of the dental implant placed in alveolar bone depends on a viscoelasticity of peri-implantium. When there is no soft tissue and is a direct structural and functional connection between the surface of implant body and the alveolar bone, which is considered to have a pure elasticity, the load and displacement of the implant is in proportion to each other. When not a proportional but a creep characteristic can be observed in a recovery response after a sudden removal of load, it is assumed that there is soft tissue surrounding the implant body but no direct connection. Thus, it is difficult to evaluate the implant, which does not have such a periodontium as a periodontal membrane of natural teeth, with the same tactile sense used to examine natural tooth.

The authors proposed an automatic diagnosis system of tooth mobility in order to measure a biomechanical properties of periodontium of natural teeth [7]. Applying a small random vibration onto labial crown of a tooth, a mechanical mobility (a reciprocal of mechanical impedance) is obtained and then viscoelasticity of periodontium are calculated. The diagnosis system is detailed as follows : The tooth is randomly vibrated with 30 - 1000 Hz. The acceleration and force of vibrating point are detected and a fast Fourier transform (FFT) processing is performed for both signals. The spectrum of mechanical mobility (an integral of acceleration / force) is obtained. Noyes and Solt proposed a biomechanical model [12] (two masses m_1, m_2, two dashpots c_1, c_2 and a spring k) of the periodontal tissues shown in Fig.1. The five parameters are calculated from the measured spectrum by a curve-fitting method. As c_1, c_2 and k correspond well with viscoelasticity of the periodontal membrane, which dominates the tooth mobility, these parameters are chosen and expressed as a new mobility triangle figure (MT figure). The MT figure provides a visual interpretation of the mechanical parameters. The centroid of the equilateral triangles is 0 and each vertex represents the normalized mean for the parameters in the healthy periodontium of the tooth. As periodontal disease advances, the MT figure shrinks and the parameters decrease accordingly. c_1, c_2 and k of healthy periodontium (MO) of maxillary central incisor are 26.1 [Ns/m], 310 [Ns/m] and 16.1 [$\times 10^4$N/m], respectively. The reproducibility of the system is 6.89 % in coefficient of variation (standard deviation / mean value).

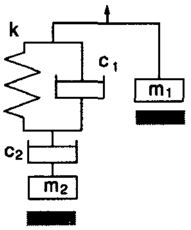


Fig. 1. Biomechanical model proposed by Noyes and Solt [12].

3. BIOMECHANICAL PROPERTIES OF THE PERI-IMPLANTIUM

With this diagnosis system, the surface of the prosthetic restoration placed on the implant is subjected to random mechanical vibrations in the facio-lingual direction, and the mechanical mobility spectrum is computed from the force and acceleration of the vibrating point. The biomechanical properties of the peri-implantium are then evaluated using viscoelastic parameters [7].

3.1 Endodontics Endosseous Implants

Fig.2 shows the postoperative radiograph of a titanium pin endodontics endosseous implant in a maxillary right central incisor. The solid line in Fig.3 shows the mechanical mobility spectrum

Fig.2. Postoperative radiograph of a titanium endodontics endosseous implant for a maxillary right central incisor.

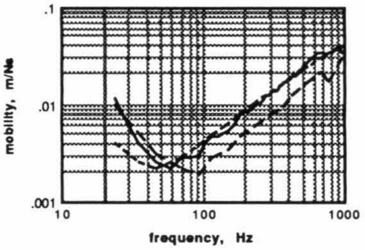
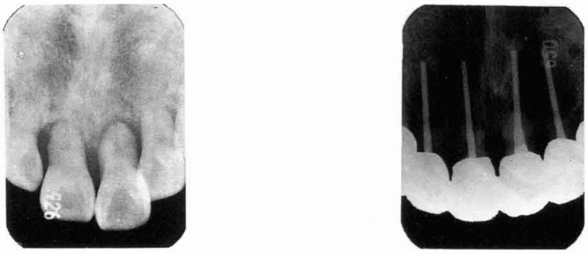


Fig.3. Mechanical mobility spectra of the endodontics endosseous implant for the right central incisor (solid line), for the the healthy left central incisor (broken line), and after curve fitting using a biomechanical model (dotted line).

of this implant 22 days after placement where a bone defect had been restored by hydroxyapatite. The broken line in the figure is the healthy left central incisor in the same patient. It can be seen that similar spectra were obtained for the endodontics endosseous implant and the natural tooth. The dotted line is the spectrum of the endodontics endosseous implant following the curve-fitting method using the biomechanical model. The viscosity constants c_1 and c_2 were 24.3 and 487, respectively, and the elasticity k was 152. The objective tooth mobility [7] was diagnosed as M1. In contrast, the same three constants for a healthy incisor would be 38.9, 550, and 32.6, respectively.

Fig.4 shows pre- (a) and postoperative (b) radiographs of endodontics endosseous implants in four maxillary incisors. There was resorption of the roots, reduction of the height of the alveolar bone, and resulting loss of periodontal support in the second premolars and the six anterior teeth in the maxilla. Clinical mobility of the central incisors was diagnosed as M3. Fig.5 shows the mechanical mobility spectra of the right (solid line) and left (dotted line) central incisors after implantation. It is clear that the right central incisor had recovered to an objective tooth mobility of M1 and the left to M0, by means of the endodontics endosseous implantation.



(a) preoparative radiograph (b) postoperative radiograph

Fig.4. Preoperative (a) and postoperative(b) radiographs of endodontics endosseous implants in the four maxillary incisors.

3.2 Endosseous Implants

As with endodontics endosseous implants, the mobility of endosseous implants is different from that of natural teeth which are supported by a periodontal membrane. This difference is for the most part determined by the composition and physical properties of the pseudo-periodontal ligament at the interface of the alveolar bone and the implant. Although it is different for each endosseous implant, and comparison of individual cases may be difficult, qualitative evaluation of the peri-implantium seems possible. It can be conjectured that in cases where the viscosity is very small, the peri-implantium has a purely elastic character, and has at least partial osseointegration [3]. Fig.6 shows the radiograph of a screw endosseous implant (Bioceram, 4AOL) for a maxillary left canine in a case where both the central and lateral incisors and the left canine were missing. The solid line in Fig.7 shows the mechanical mobility spectrum for this implant and the broken line shows the corresponding values for the natural tooth on the opposite side. The dotted line represents the mechanical mobility characteristics of the endosseous implant following the curve-fitting method using the biomechanical model.

As was the case with the endodontics implant, mechanical mobility characteristics similar to those for natural teeth were obtained. The clinical mobility was M0 and the constants c_1, c_2 and k were 35.9 and 608, 152, respectively. The corresponding values for natural canines are M1, 12.9, 311, and 14.0. Since the elasticity k for the implant was very large, it was assumed that the implant had a peri-implantium. Fig.8 shows the so-called mobility triangle (MT) for a screw endosseous implant (Bioceram, 3AOL) for a maxillary right lateral incisor. The implant had been splinted to the adjacent central incisor with ceramometal crowns placed with temporary cement. The solid lines in the MT figure are from the first measurement which was obtained 9 months after implantation. The dot-dashed lines represent the second measurement, which was

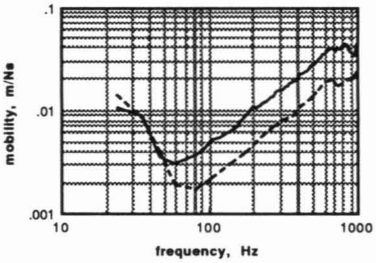


Fig.5. Mechanical mobility spectra for endodontics endosseous implants in the right central (solid line) and left central (dotted line) incisor.

Fig.6. Postoperative radiograph of a Bioceram implant for a left canine.

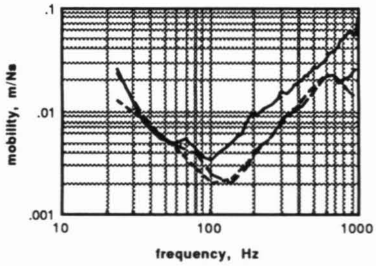


Fig.7. Mechanical mobility spectra for a screw endosseous implant for maxillary left canine (solid line), the natural canine on the opposite side (broken line), and after curve fitting using a mechanical model (dotted line).

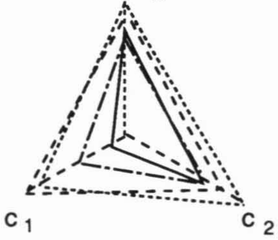


Fig.8. Mobility triangle (MT) for a screw endosseous implant for a maxillary right lateral incisor. The solid lines were obtained 9 months after implantation, the dot-dashed lines 7 days later, and the dotted lines 96 days after that.

made one week after the first. The dotted lines show the values recorded 96 days after the second measurement. The broken lines show the mean values for a natural tooth with healthy periodontium. It can be seen that the condition of the peri-implantium recovered to that of a healthy tooth in about one year. The postoperative course of this endosseous implant splinted with a natural tooth has been successful. The MT was valuable asset in evaluating the progress of this endosseous implant.

4. INTRAMOBILE CYLINDER IMPLANTS

The intramobile cylinder (IMZ) implant, with its unique stress absorbing element (IME), was designed in 1970 and has been used in clinical practice since 1978 [13]. It is a stress breaking mechanism which acts as a shock absorber, distributing stresses in the endosseous implant [14]. Thus it plays the role of the periodontal membrane for the endosseous implant which has attained osseointegration. Fig.9 is the graphical representation of an IMZ implant which has been placed in plaster. Fig.10 shows the MT figure when polyoxymethylene resin IME (solid line) and titanium (dotted line) were used as the insert. The broken lines show the mean values for a tooth with healthy periodontium. Although the values of the parameters with the resin were slightly greater than those of a natural tooth, the elasticity for the titanium was about double that of the natural tooth. These results indicate that the IMZ functions as a stress breaker to horizontal loads and is effective as a buffer for the osseointegration of endosseous implants. However, tests should be carried out in the future on this system using actual clinical cases since the results from implants in plaster are not sufficient.

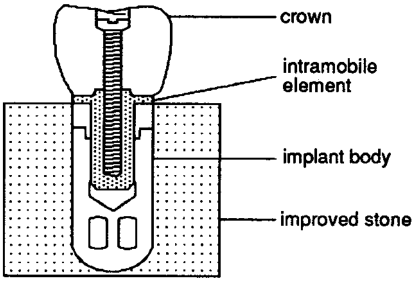


Fig.9. Intramobile cylinder (IMZ) implant embedded in model plaster.

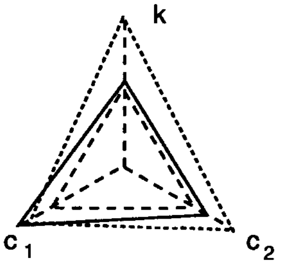


Fig.10. MT for the polyoxymethylene resin IME (solid line) and titanium element (dotted line).

5. CONCLUSIONS

The tactile sense during palpation for mobility in natural teeth is different from that in dental implants. The automatic diagnosis system for tooth mobility discussed here is very effective in the quantitative evaluation not only of the condition of an implant but also in the evaluation of changes which occur in implants over long periods of time.

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