RESONANCE FREQUENCY ANALYSIS FOR OSSEOINTEGRATION IN FOUR SURGICAL CONDITIONS OF DENTAL IMPLANTS

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Abstract-**The establishment of osseointegration following dental implant placement is a major contributing factor to the clinical success and long-term function of implant-retained prosthesis. Radiographic examination and palpation have been two of the methods often used in clinical assessment for implant stability for years. However, theses radiographs are two-dimensional and difficult to standardize. The investigation was designed to study the use of resonance frequency analysis in search of the stability of the implant-tissue interface in vitro. Resonance frequency was measured when test implants were embedded in bakelites. The change in stiffness observed during bone healing was modeled by embedding implants in gypsum during setting period. Our results showed that there was an increase in resonance frequency related to stiffness increment during osseointegration.**
***Keywords* –dental implant, osseointegration, resonance frequency, stability**

I. INTRODUCTION

Dental implants are being used increasingly to provide support and retention for prostheses replacing missing teeth in edentulous and partially dentate patients [1]. Clinical success of dental implants depends on osseointegration. Osseointegration has been defined as “a process whereby a clinically asymptomatic rigid fixation of alloplastic materials is achieved and maintained in bone during functional loading [2].” There are many reasons for implant failure, such as inherent factors related to the design of the implant system, a poor placement technique, or an adverse host response, and excessive clinical loading. Clinically, failure can be manifested in a number of ways: by an increasing, progressive mobility of the implant, by a decrease in the height of the surrounding marginal bone and by fracture of implants components.

Adequate stability of an implant is essential to allow bone formation following placement. The stability requirements for healing and function are different. Clinically, primary stability is an important factor for implant success at the time of implant placement. Primary stability can be determined by the density, quality of the bone, the surgical technique, and the geometry of an implant. If an implant is not sufficiently stabile at the time of placement, the normal healing process may be disrupted and a subsequent clinical failure may occur [3]. Secondary stability often refers to implant stability after primary stability has achieved. The further increase of stability is a direct result of the regeneration and remodeling processes at the implant-tissue interface. Establishment of secondary stability allows an implant to distribute loads transmitted by the intraoral prosthesis to surrounding bone. Nevertheless, implants with poor primary stability may need longer healing periods to achieve sufficient secondary stability.

Clinically, it is highly desirable to have a quantitative method to measure establishment of the implant stability. Such information can then be used to determine the optimum healing period, which make a more effective and less time-consuming implant treatment possible. To date, relatively few clinical techniques are available to provide quantitative information. Those, which are now available, will be discussed shortly below.

For years, radiographs are the most widely used clinical technique for the evaluation of osseointegration. The objective of radiographs is to identify peri-implant radiolucency. However, the accuracy and precision in the radiographic diagnosis of clinical instability in dental implant are not sufficient, when bone density loss is less or equal than 30% [4]. Moreover, quantitative evaluation for radiographs is difficult, because X-ray incident angle and processing procedures are also not easy to maintain.

The percussion test is another common method for implant stability measurement. The method is performed by tapping a fixture mount or an abutment with a metallic instrument. The change in the percussion sound can indicate whether the implant has good or bad stability. However, the intrinsic nature of such test is subjective, and is relatively insensitive to changes in implant stability [5].

Resonance frequency has been used to evaluate bone loss in orthopedic medicine for many years [6,7]. Meredith et al. proposed a non-invasive vibration method whereby bone formation at the bone-implant interface could be studied in vivo condition by measuring the resonance frequency of a small transducer attached to an implant fixture [6]. They suggested that changes in the stiffness of an implant during healing of 6 month or more could be monitored.

Nowadays, the problem for clinical implantology is focused on how to measure implants stability. The optimal healing time needed to retain long-term stability of implants in poor bone quality is unknown, and so dose the influence from the surgical procedures itself. The purpose of this investigation was to evaluate the possibility of using resonance frequency measurement to monitor changes at the implant-tissue interface in different boundary conditions during osseointegration.

II. METHODOLOGY

The key feature of the current diagnosis method is to attach a sensor to an implanted fixture by the use of a healing screw

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Resonance Frequency Analysis for Osseointegration in Four Surgical Conditions of Dental Implants	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Graduate Institute of Oral Rehabilitation Sciences Taipei Medical University Taipei, Taiwan	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom. , The original document contains color images.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
4

(Fig. 1). The sensor is comprised of a motor attached to two piezoelectric films. The sensor receives vibration from DC motor with a low-voltage electric current and the response being measured by the piezoelectric film. The device driver and signal detection are programmed by a personal computer. The first resonance frequency of the system was observed.

There are four surgical models prepared in current study, which includes: Standard Type (ST), Sinus Lifting Type (SLT), Immediate Implantation Type (IIT), and Floating Type (FT). ST model is the idealized condition for standard implantation, a tight contact between implant and alveolar bone (Fig. 2a). When vertical bone in maxillary posterior segments is not sufficient, sinus lifting technique is often used to augment the bottom of the maxillary sinus with bone graft, to find sufficient anchorage for dental implants. In SLT model, the cervical portion 4mm from the top of dental implants are contact with surrounding alveolar bone and the rest of dental implants are surrounded by bone grafting materials (Fig. 2b). Placement of an implant immediately following loss or extraction of a tooth is called as the immediate implantation technique. In IIT model, the cervical third of dental implants are contacted to bone grafting materials, and apical third of dental implants are contacted to solid alveolar bone (Fig. 2c). As for FT model, it represents the condition that there is no contact between dental implants and alveolar bone. Model material for blood clots and bone grafts will fill the space between implants and adjacent alveolar bone (Fig. 2d). FT model represents the condition occurred at implant failure, which connective tissue growth around the implant instead of bone.

Changes in stiffness was modeled by inserting a 10 mm implant in length, and 3.75 mm in diameter in bakelite pre-cut the dimension of 10 mm×10 mm×15 mm, the center drill hole had been filled with type gypsum prior to the implant installation. The gypsum was allowed to set in room temperature, meanwhile resonance frequency of the system was measured at 1 min intervals from the 5th min to the 40th min after mixing the gypsum.

It was proposed that the density at the bone-implant interface would influence the resonance frequency of the system. Variable concerning bone density variation was modeled by the resonance frequency measurement when filling the implant-bakelite interface with plaster and silicone in SLT and IIT models. Because the density of silicone is lower than that of plaster, we use silicone to simulate low-density bone.

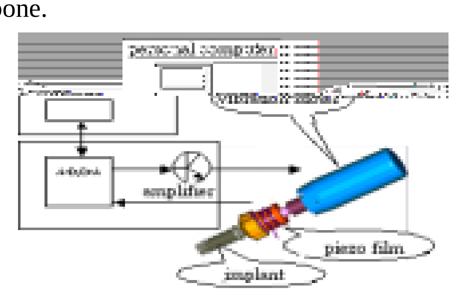
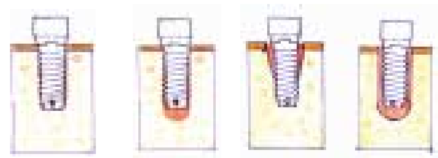


Fig. 1. Schematic diagram of resonance frequency measuring instrumentation.



(a) (b) (c) (d)

Fig. 2. Diagram of four surgical models: (a) standard type (b) sinus lifting type (c) immediate implantation type (d) floating type

III. RESULTS

Fig. 3 showed the changes in resonance frequency during the setting of gypsum. The starting resonance frequency, ending resonance frequency and percentage change in resonance frequency of four experimental models is illustrated in table 1. It is observed that FT model need more time than IIT model when comparing the time from start to plateau stage of resonance frequency.

The resonance frequency during setting for plaster and silicone interface fillers is illustrated in Fig. 4. In general, the resonance frequency of implants embedded in silicone is lower than that embedded in plaster.

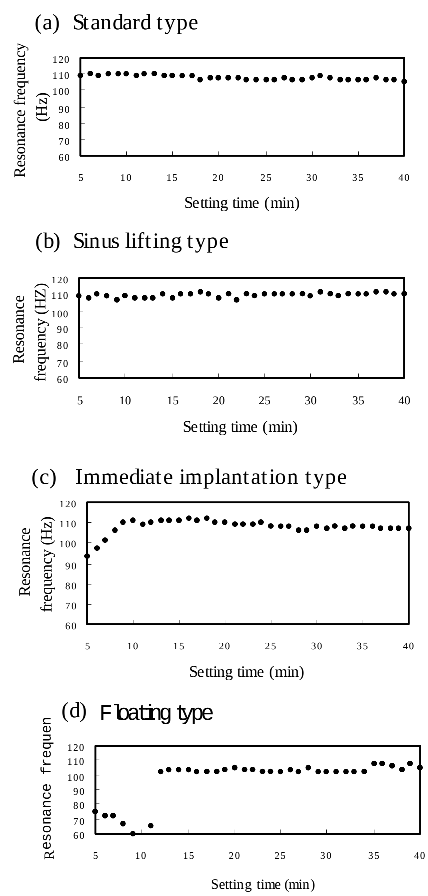
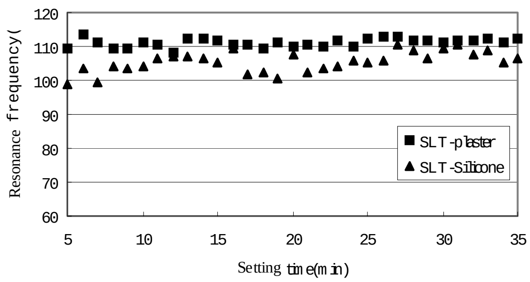


Fig. 3. Variation in resonance frequency with setting time for implant embedded in type gypsum.

TABLE 1
RESONANCE FREQUENCY OF FOUR MODELS

	starting frequency	ending frequency	* change percentage
types	(Hz)	(Hz)	(%)
ST	109.5	105.8	-3.4
SLT	109.0	110.6	1.5
IIT	93.0	107.3	15.4
FT	75.5	104.5	38.4

$$\text{*change percentage} \quad \frac{\text{starting frequency} \quad \text{ending frequency}}{\text{starting frequency}} \times 100\%$$



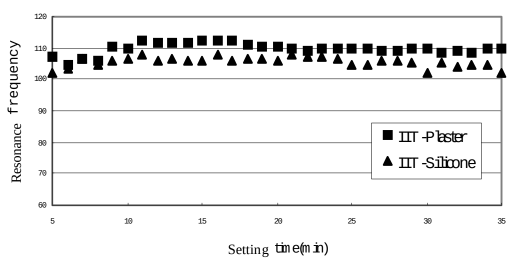


Fig. 4. Resonance frequency versus setting time for plaster and silicone.

IV. DISCUSSION

Four proposed experimental surgical models represent possible anchorage conditions for dental implants. The tightness at the implant-bone interface of ST model was relatively high, which ensures a space-free interface. Therefore, the starting frequency of ST model was the highest when compared the rest of the three models. The starting frequency of FT model was the lowest, which came as the result from a lack of direct contact between implants and embedding block before the setting of plaster. Although the contact length of SLT and IIT are the same, the resonance frequency of IIT model is lower than that of sinus lifting type due to a lower contact position, i.e. longer effective vibration length. Meredith et al. reported that resonance frequency was related to the implant effective vibration length [9]. Our experimental result, showed that the starting stability under different surgery conditions can be measured by the self-designed diagnosis system, which can be used as the reference standard for implant following up.

Changes in stiffness at the implant-tissue interface during bone formation and healing was modeled using the change solidification process that occurs during the setting of gypsum. The results showed an increase in resonance frequency when plotted against setting time. This indicates that our system is sensitive to changes in stiffness as the hardening of the gypsum progressed. These finding will need further investigation to test for the applicability of such device to monitor changes at the implant-tissue interface during healing. Irrespective of model type, the resonance frequency after the completion of bone healing would be almost the same. Therefore, the starting resonance frequency will be the dominant factor, which affects the percentage increment in resonance frequency measurement during healing. In IIT model, the starting resonance frequency is the lowest among these three types and the percentage change of resonance frequency is the greatest.

In situations with poor primary stability like FT, healing process would play a major role in providing the secondary stability, because a great part of the implant surface is not in direct contact with bone at initial placement period. Due to the fact that stiffness of connective tissue is lower than that of bone, the final resonance frequency at plateau stage of FT was lower than the others.

In this study, the resonance frequency of ST decreased with setting time (Table 1). The change in stiffness during gypsum setting was minor that the system is not sensitive enough to measure it, which might caused from the relatively thin layer of gypsum in the implant-block interface. The amount of gypsum luting the implant-block interface represents the volume of new bony formed during bone healing. When Compared the volume of bony defect around the dental implants between IIT and FT. FT model will need more time to complete osseointegration, because it contains larger area of bonny defect. Consequently, our experimental result implied that implant with poor primary stability would need longer healing periods to achieve the secondary stability.

Olive et al. observed that implant mobility decreased at the fourth month after abutment attachment [10]. This means that the newly formed bone is immature in second stage surgery. Clinically, the application rule, suggested by Brnemark et al, that osseointegration will take six months in maxilla and three months in mandible may be controversial. [11]. In fact, due to variations from different surgical and bone conditions, the time needed for osseointegration would differ from one to the others [12]. To prevent late implant failure, it is suggested that clinicians should adopt the use of resonance frequency at the time of abutment attachment. If resonance frequency at that time is too low, the patient should wait until better osseointegration level has being achieved.

The sensitivity of our detection system to different filling material was observed by embedding implants in silicone and plaster. Plaster represented bone with high density and low elastic modulus such as cortical bone. During setting procedure, the resonance frequency of plaster was higher than silicone. Implants in higher density bone are more stable.

Adell et al. reported that the success rate of implants in mandible was higher than implants inserted in maxilla [13]. The reason is that bone density is higher in mandible than that of maxilla. Implant is more stable in mandible and the success rate is higher.

The results indicated that this technique is sensitive to different initial stability and changes in stiffness as the gypsum setting progressed. These finding will call for further investigation, as there may be potential to monitor changes at the implant-tissue interface during healing.

V. CONCLUSION

Resonance frequency analysis technique is capable of eliciting quantitative information related to implant stability and stiffness. Using resonance frequency to evaluate osseointegration is benefit in clinical examination.

ACKNOWLEDGMENT

The work re supported by National Science Council, NSC-89-2213-E-038-007.

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