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(Original article)

Development of a microcontroller-based dental implant movement checker

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Summary

The aim of this study was to develop a portable device (IM checker) for measuring dental implant mobility using a microcontroller. A constant amplitude and frequency vibration was applied to a dental implant model and the acceleration signal was detected using measuring probe. Then the IM score was obtained using the criteria developed in this study. We made several implant models of different implant lengths, diameters and material of Rigolac® or Molteno® . There was a linear relationship between mechanical mobility at 400 Hz of the models and the IM scores (R^2 = 0.92). The IM checker could discriminate the mobility of dental implant models in twelve measurements with $P < 0.01$. There was no significant difference in the means of the IM score measured by four operators with $P < 0.01$. The results indicated that the IM checker had sufficient reliability and could be available in dental clinics.

Keywords : Tooth mobility, mechanical mobility, dental implant, manual examination

Introduction

Nowadays the use of dental implants has been increasing, because they offer an excellent alternative to the limitation of conventional dentures or bridges, especially in term of functional and esthetic advantages. They act as a secure anchor for artificial replacement of missing teeth and eliminate the instability, which usually happens in dental dentures or bridges.

Tooth and implant mobility are important diagnostic aids in determining and assessing periodontal disease and dental implant stability. A quantitative evaluation of dental implantation is not established yet in clinics[1]. Biomechanical properties of connective tissue in vivo are difficult to obtain without the use of invasive techniques[2]. However, there have been many studies on noninvasive and nondestructive test methods for assessing dental implant and tooth mobility[3-8].

The most commonly clinical diagnoses for assessing and evaluating implant placement, osseointegration and abutment fit are a manual examination and radiographic techniques. However, the manual examination is very subjective and radiographic techniques are limited due-to two-dimensional information and very difficult to stan-

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dardize[9]. d'Hoedt, *et al.* developed Periotest® (Siemens GmbH) to perform quantitative measurement of the damping characteristics of periodontal ligament surrounding of a tooth to get its mobility objectively[3]. Though it was specially designed for tooth mobility, some used it for assessing dental implant mobility as well. The typical values for implant mobility indicate in the narrow range over its broader possible range in the Periotest values. Therefore, the use of Periotest for clinical aid for assessing implant mobility is limited due to the lack of its resolution and poor sensitivity[9]. Kaneko *et al.* used two puncture needles, which acted as a driver and a receiver. Pulsed forces were applied at 10 - 150 kHz range from the driver to induce implant to vibrate at the implant bone-interface[4]. The receiver obtained recoil signals, amplified and display on the oscilloscope screen to get the resonance frequency. This technique found difficulty in setting and arranging the two needles. Moreover, it depended on load direction and position of the needles. Meredith *et al.* used the information of resonance frequency of dental implant alone to assess implant mobility[7]. Ramp *et al.* utilized non-linear dynamic response to assess the state of osseointegration by mapping the effective impedance as a function of applied load[8]. It was suspected that both of their techniques had disadvantage especially in the difficulty of measurement set up which made less convenient for patients.

The aim of this study was to develop a dental implant movement checker, which was portable, reliable and easy to operate. We had already developed a digital-based implant movement checker for estimating implant mobility[1]. We replaced the need of note-type PC to a microcontroller in order to be portable and more reliable. The same principles and methods in designing a microcontroller-based IM checker were used as in the digital-based one. In this study, we focused on designing of microcontroller-based IM checker; modified data acquisition system in order to get faster response. It was also verified the reliability and performance of the device, selected appropriate implant models to be standard of implant mobility measurement.

Methods

1.Mechanical mobility and IM score

By applying random vibration on tooth or a dental implant, the mechanical mobility, $\lambda(f)$ can be obtained. The $\lambda(f)$ is defined as the ratio of velocity and force at driving point[10] as follows:

$$\lambda(f)=\frac{V(f)}{F(f)}=\frac{1}{j\omega}\frac{A(f)}{F(f)} \tag{1}$$

where $\omega=2\pi f$, $V(f)$, $F(f)$ and $A(f)$ are the Fourier transform of the velocity $v(t)$, the applied force to the mechanical system, $f(t)$ and the acceleration, $a(t)$, respectively. The measurement of mechanical mobility was made using the automatic diagnosis system of tooth mobility for clinical use, and the mechanical mobility spectra were obtained[11]. The measuring tip of the device was vibrated by a random signal generator ranging from 30 Hz to 1000 Hz. The acceleration and force signals at the driving point were obtained using the measuring probe. The signals were fed into an analog to digital converter (ADC) and processed by Fast Fourier Transform (FFT) algorithm.

In the IM checker, the implant movement score, IM was defined, that is proportional to the acceleration signal when a measuring frequency and applied force at driving point are kept constant as

$$IM=k'A. \tag{2}$$

In this equation k' is the proportionality constant, and A is the acceleration at the applied frequency, respectively. It was already described in the previous works that the acceleration was proportional to the mechanical mobility, and then the IM score was also proportional to the mechanical mobility[1]. The range of IM score was designed between 0 (the least mobile implant movement) to 99 (the most mobile implant movement).

2.Design of microcontroller-based IM checker

1) Hardware design

The hardware design of the microcontroller-based IM checker was divided into three units, namely: measuring probe, amplifier unit and

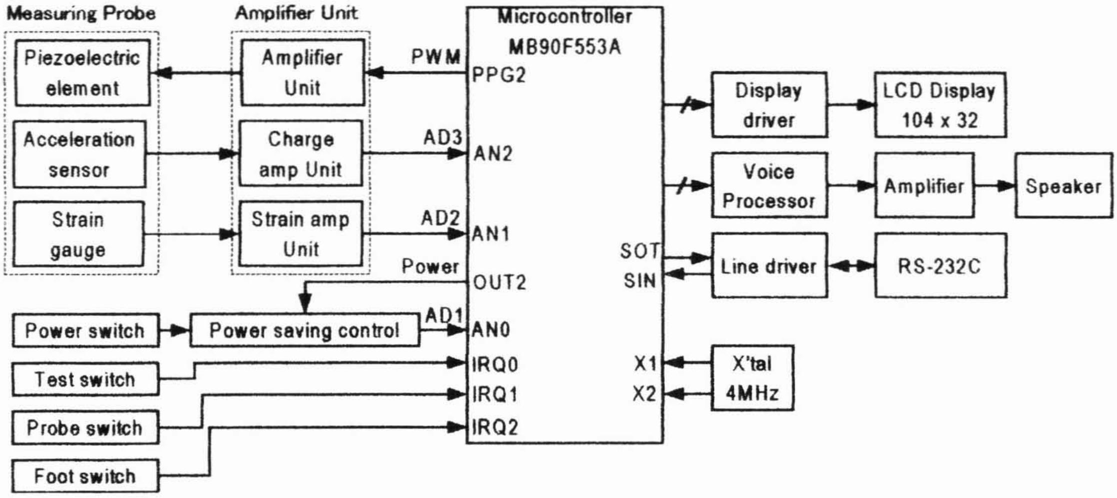


Fig. 1 Block diagram of the microcontroller-based IM checker.

microcontroller system as shown in Fig. 1. In this study the F^{2}MC MB90553A microcontroller was used. It was a 16-bit general-purpose real-time microcontroller. The main features of the microcontroller are 8 channels of 10-bits ADC with conversion time 26.3 μs and 8 priority level programmable interrupt function of 8 channels external interrupt inputs.

The new system provided a foot-switch for starting and canceling measurement, so that an operator could easily measure implant mobility without any assistance. A probe switch was also provided for detecting the measuring probe whether on hook or off hook. The indicators for measurement result were LCD display and speaker.

The size of measuring probe was similar to a dental drill, which consists of an actuator, acceleration and preload transducer. The design has been reported previously[12]. When an implant of the model is vibrated, the resulting acceleration signals were obtained by the acceleration transducer of the measuring probe, and the preload signals were obtained by strain gauge of the measuring probe. These signals were obtained during measurement, and they are very low and need amplification of charge and strain amplifiers, respectively. The output from charge amplifier was fed into band-pass filter (BPF) and followed by an RMS/DC converter to get the mean value of acceleration signals. Later this signal and the output signal from the strain amplifier, which passed trough LPF, were fed into the microcontroller to be processed by the program as described in the software design. The photograph of the developed microcontroller-based IM checker and the measuring probe is shown in Fig. 2.

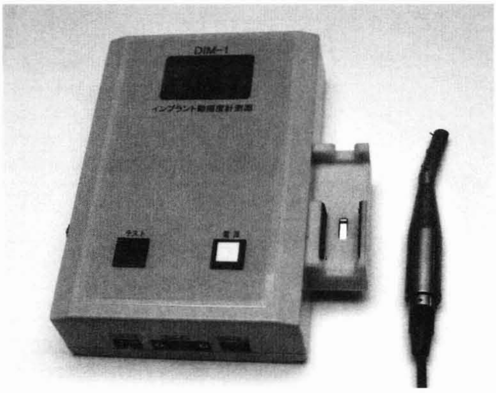


Fig. 2 Photograph of the microcontroller-based IM checker and the measuring probe.

2) Software design

When the measuring probe actuates an implant, the preload and acceleration response are detected for every 1 ms and stored into $g[n]$ and $a[n]$ respectively. The microcontroller feature of interrupt driven I/O was utilized in order to get faster acquisition data as soon as measuring probe touched an implant.

The program accumulates data if the preload and the acceleration response are satisfied in the range of $(50 \pm gLSB)$ gf and $amean \pm aLSB$, where *amean* is the mean value of a series of acceleration response in one data sampling, *gLSB* is for variation of permitted range of the preload and *aLSB* is for variation of permitted range of the acceleration. It was assumed that a 50 gf preload was low enough and would not give any pain to a patient when receiving the contact pressure. So, it was considered as nondestructive and noninvasive method. In this design, 100 data were sampled as one unit of data sampling.

After initialization process, the measuring probe is ready to use. Just before measuring (for about 100 ms), the non-contact preload was obtained first as the reference condition. Therefore, the IM checker could measure the implant mobility at any direction. After that, it sets all of the parameters, indicates measurement flag, and begins acquisition acceleration responses and checks contact preload. There are three different pitches according to the preload range. They are above, below or in the range of the criteria, so that the operator can easily adjust the correct preload range. This program accumulates 10 times of mean values of acceleration signals. Only data in the range of the criteria are accumulated and processed. The accumulation of the mean values of acceleration signals are averaged and displayed as the IM score on the LCD panel and in the speaker as human voice. The measurement time should be smaller than 10 s, for the comfort of the patient. The flowchart of the software is given in Fig. 3.

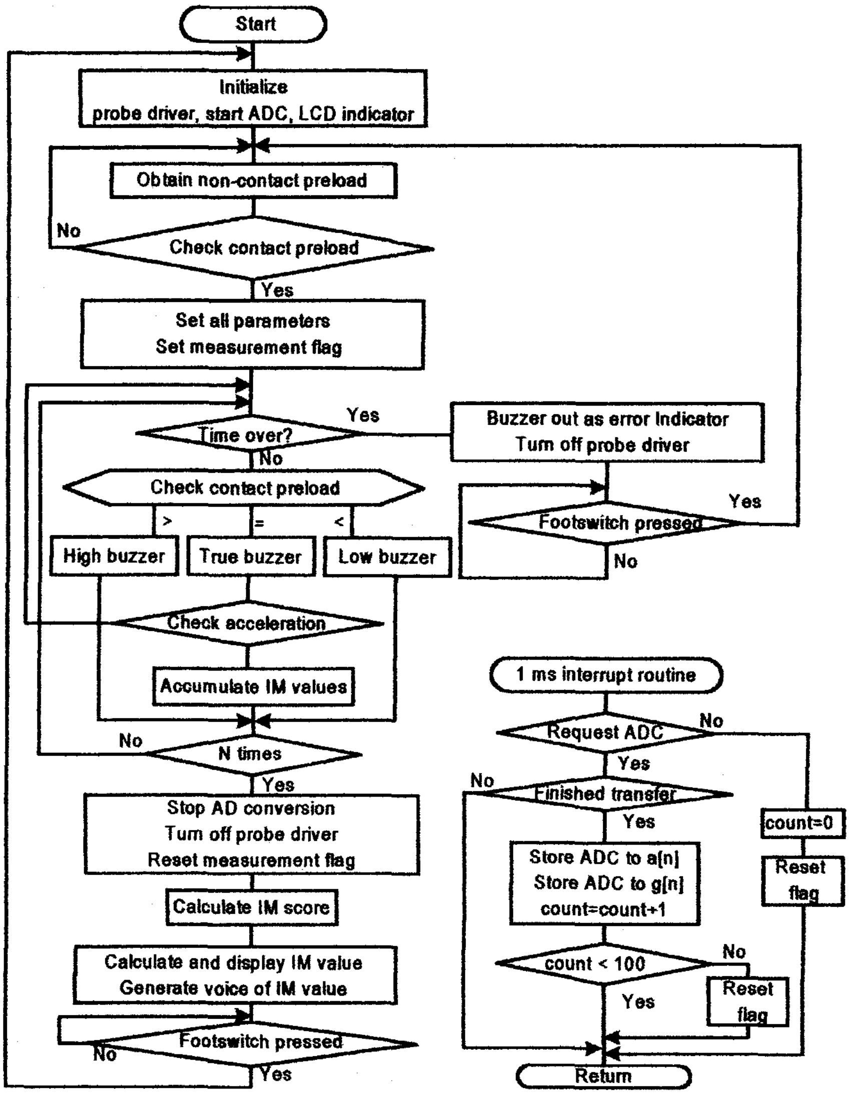


Fig. 3 Flowchart of data acquisition of the microcontroller-based IM checker.

3.Artificial implant models

In order to check the reproducibility and performance of the developed IM checker, several implant models of different mobility were made. It was made two different types of implant models, one was Molteno-based material and the other was Rigolac-based material. These materials were used to simulate the interfacing behavior of dental implant to alveolar bone.

The models were made at certain composition which consisted of Rigolac base material 2004WMB, Softener 70F, Hardener and Quickening agent. The hardener and quickening agent were fix at 1% of weight, while the percentage Rigolac base material was varied. The hardening process was done in room temperature and followed by curing procedure for 8 hours in oven of 70 ℃. The sticky surfaces were scoured and followed by another 2 hours of 70 ℃ curing process. Each model was 7.0 × 7.0 × 4.0 cm in size and 220 g in weight. It was assumed that the edge effect would not occur in this size.

4. Experimental methods

1) Asker hardness index of materials

There were 10 dental implant models of different lengths, diameters, and stiffness. Each of the implant models was made of different material. The Asker hardness index of the material in C2-scale was measured using the Durometer. Each of the implant models was measured at 5 different positions in order to get more valid result of Asker hardness index.

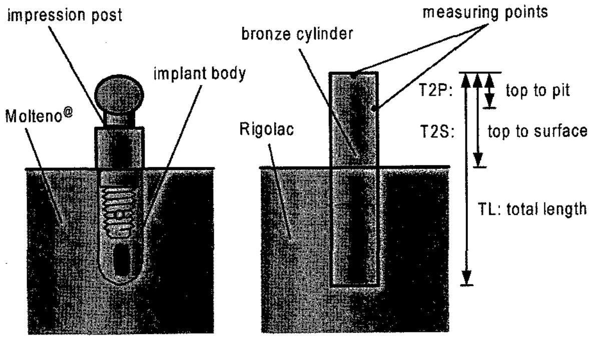


Fig. 4 Dental implant models.

2) Mechanical mobility spectra of implant models in different conditions

Mechanical mobility spectra were obtained using the automatic diagnosis system of tooth mobility for clinical use[11]. The implant models were vibrated in the perpendicular direction and axial direction at marked points for five times. All measurements were done in the same condition in which the models were fixed using a vice.

3) Mechanical mobility spectra of healthy teeth

The typical mechanical mobility of healthy teeth was obtained using the automatic diagnosis system of tooth mobility for clinical use. Teeth with periapical affected caries or periodontal disorders might show "false" mobility. The subject is a 22-year-old male with no-decay anterior teeth. Each right anterior maxillary tooth (central incisor, lateral incisor and canine) was measured in perpendicular direction three times by an experienced operator. The spectra were supposed to be as the references of mechanical mobility spectra. The mechanical mobility spectra of dental implants, which should be in the range of mobility of healthy teeth, were compared to these references.

4) Optimum conditions of IM checker

The IM checker provided parameters (*gLSB* and *aLSB*) to adjust the sensitivity and accuracy of the measurement. The optimum condition would be the least variation and the least measuring time over different the IM checker parameters. Each of the parameter was varied. The IM score and the measuring time of the Molteno-base dental implant models were obtained using the different parameters. The measuring time is the time required to get the IM score after pressing the foot-switch until the IM checker displayed and generated measurement result to the LCD and the speaker. The measuring time measurement required the help from other operator. Each measurement was done 12 times simultaneously by the same operator.

After the optimum parameters for the IM checker were found, all the other IM score measurements were done using these parameters. From the previous measurement of mechanical mobility spectra of the implant models, the magnitude of mechanical mobility at 400 Hz could be obtained. The relationship of the IM score to the mechanical mobility was necessary to obtain in order to verify the validity of the definition of IM score.

5) Measurement reliability among operators

In order to check the reliability of the microcontroller-based IM checker, Molteno-based models were measured by four different operators. Each operator measured the two models at different direction for 12 times simultaneously. The significant differences were determined using t-test. Possible correlations between pairs of parameters were analyzed using linear regression analysis.

6) Comparison to Periotest

Comparison the measurement result to the commercial device was done using the Periotest. The comparison was held in perpendicular direction only, since the Periotest was unable to measure in axial direction of the implant, or otherwise the models had to put and lay down in horizontal orientation. Changing this orientation introduced different condition of measurement, so it might be difficult to compare.

Each model was measured using Periotest 12 times simultaneously by the same operator, in the same condition and at the same measuring point as measured using IM checker. All models were fixed using a vise while measuring.

Results and Discussions

1. Asker hardness index of materials

It was found that there was a linear relationship (R^2= 0.856, P < 0.0001) between stiffness and Rigolac percentage weight of 2004WMB as it is shown in Fig. 5. The increased percentage weight of Rigolac 2004 WMB increased the stiffness of the implant surrounding. Therefore, it was possible to make different stiffness of the implant surrounding of the model according to the percentage of weight of Rigolac 2004WMB.

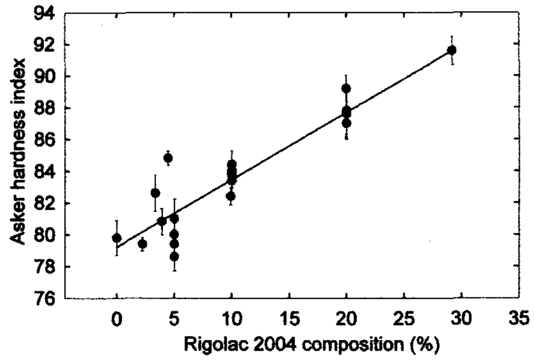
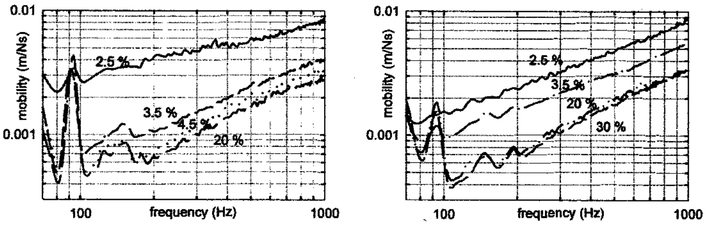


Fig. 5 Asker hardness index of Rigolac-based implant models in different composition ratio.

2. Mechanical mobility spectra of implant models in different conditions

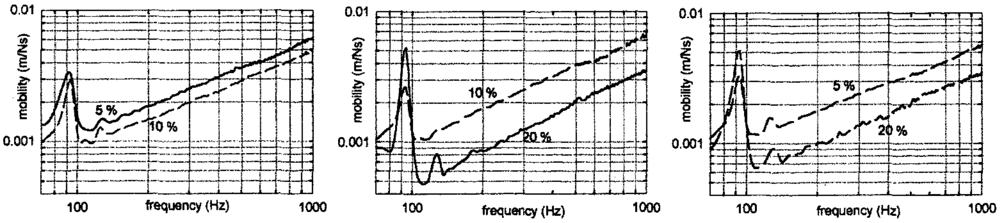
The mechanical mobility spectra of the Rigolac-based implant models are shown in Fig. 6. For the same implant dimension, as the stiffness of the material increased, the mechanical mobility decreased as shown in Fig. 6 (a) and (b). This result indicates that increasing stiffness of the surrounding material makes less mobile of the implant, since the implant fitness is more secure to the surrounding. The same result was also found in Molteno-based implant models, which had been reported previously[1]. However, as it is shown in Fig. 6 (a), there was no big differences in mechanical mobility of 20 % and 30 % ratio of Rigolac 2004WMB. At these conditions the implant are completely fitted and immobile. Beyond these conditions, there is no such condi-



(1) axial direction

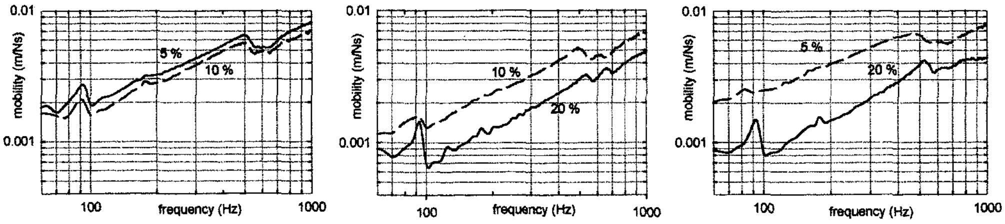
(2) perpendicular direction

Fig. 6 (a) Mechanical mobility spectra of Rigolac models for ϕ = 4 mm, total length=20 mm in different measuring condition and constitution ratio of Rigolac 2004 WMB.



(i) TL = 19 mm (ii) TL = 21 mm (iii) TL = 22 mm

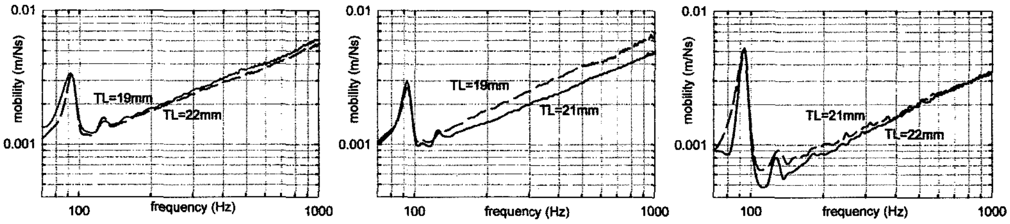
(1) axial direction



(i) TL = 19 mm (ii) TL = 21 mm (iii) TL = 22 mm

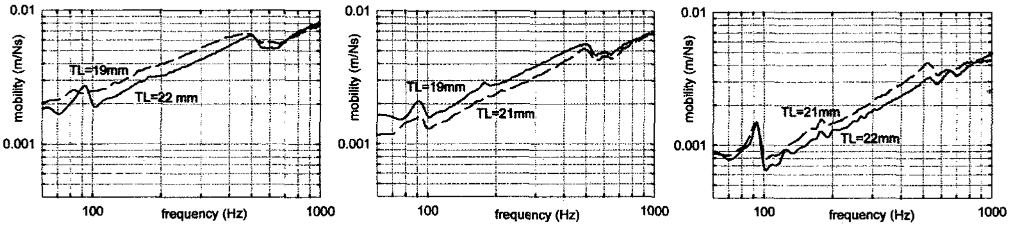
(2) perpendicular direction

Fig.6 (b) Mechanical mobility spectra of Rigolac models in different measuring direction and total length of implant.



(i) 5 % (ii) 10 % (iii) 20 %

(1) axial direction



(i) 5 % (ii) 10 % (iii) 20 %

(2) perpendicular direction

Fig. 6 (c) Mechanical mobility spectra of Rigolac models in different measuring direction and constitution ratio of Rigolac.

tion of dental implant fitted in the alveolar bone. Therefore, that it is not necessary to make a model of such condition. For the same implant surrounding, the mechanical mobility decreased as the implant length increased as shown in Fig. 6 (c). This indicates that longer implants are less mobile than the shorter one for the same condition of implant surrounding, as the implants have more surface contact. However, this condition has to be verified to the bone conditions of a patient.

Fig. 7 shows a linear relationship between mechanical mobility at 400 Hz and IM score (R^2 = 0.92). This indicates that the definition of IM score to be linear to the mechanical mobility at constant frequency is valid. As the driving frequency was 400 Hz, which was quite low to the resonance frequency of the implant[9], there was no concern on non-linearity effect[8].

3. Mechanical mobility spectra of healthy teeth

The typical mechanical mobility spectra of

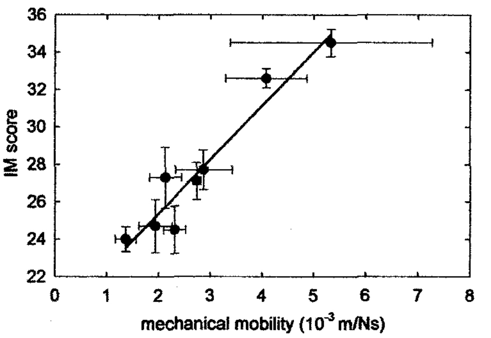


Fig. 7 The relationship between the magnitude of mechanical mobility at 400 Hz and IM score.

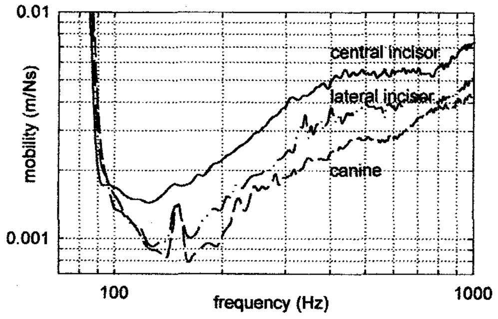


Fig. 8 Typical mechanical mobility spectra of healthy central incisor, lateral incisor and canine.

healthy teeth of central incisor, lateral incisor and canine of a 22-year-old male are shown as shown in Fig. 8. The information of biomechanical behavior of tooth in its alveolar bone or dental implant buried in the alveolar bone under the influence of forces can be obtained using a dynamic mechanical mobility measurement.

However, usually the mechanical mobility of dental implant in vivo is lower than the mechanical mobility of healthy teeth, since it does not have periodontal ligament[2]. One of the criteria of the success of dental implantation is that there is no noticeable mobility[13], which is similar to the mobility range of healthy teeth. Therefore, it is important to make dental implant models in the M0 range. The actual mechanical mobility of vital healthy teeth should be as the basic of implant mobility measurement.

It was found that all of the mechanical mobility of dental implant models was in the range of the mechanical mobility of healthy teeth by comparing Fig. 6 and Fig 8. Therefore, they could be used as reference models for measuring implant mobility using the microcontroller-based IM checker.

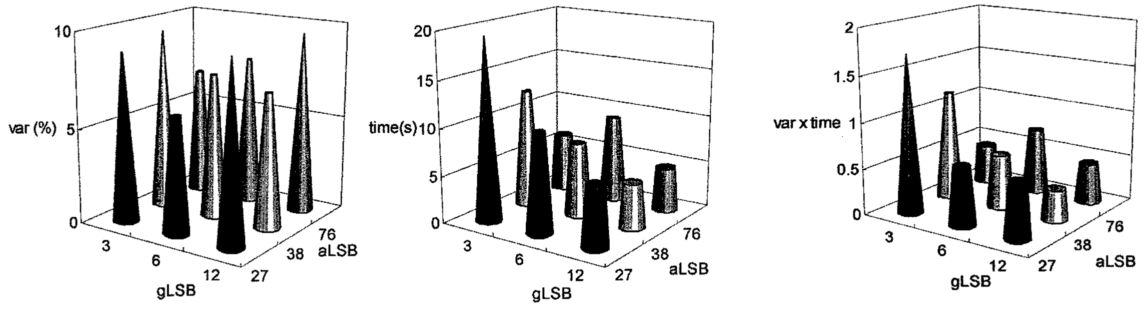
4. Optimum conditions of IM checker

The results of different *aLSB* and *gLSB* parameters are shown in Fig. 9. In most cases, for constant *aLSB*, it was found that when the *gLSB* increased the variation also increased, but the measuring time decreased. For a constant *gLSB* as the *aLSB* increased the variation also increased and the measuring time decreased. At the value of *gLSB* = 3 and *aLSB* = 27 the lowest variation was 5.8 % in the perpendicular direction (Fig. 9 (b)), however the measuring time was quite long (25.2 s). At the value of *gLSB* = 12 and *aLSB* = 76 the lowest measuring time was 4.6 s, however the variation was 9.5 % in the axial direction (Fig. 9 (a)). The optimal measuring condition was at *aLSB* = 38 and *gLSB* = 12 (variation was 7.1 %, 9.4 % and measuring time was 4.8 s, 5.3 s, respectively for perpendicular and axial direction) as shown in the Fig. 9. It was indicated as the least value of variation x measuring time. It was assumed that the measuring time and variation were in the same weight factors.

The minimum value of IM score was found (24 ± 2) for the implant model with D = 4 mm, TL = 20 mm, and WR = 20 % at perpendicular direction of measurement. The maximum value of IM score was found (54 ± 1) for the implant model with D = 3 mm, TL = 17 mm, and WR = 5 % at axial direction. The maximum variation of the IM score measurement was 8.6 % for the implant model with D = 3 mm, TL = 21 mm, WR = 20 % at perpendicular direction. The minimum variation was 1.5 % for the implant model with D = 4 mm, TL = 20 mm, WR = 10 % at axial direction. The D, TL and WR are diameter, total length of the implant cylinder, and weight ratio of Rigolac 2004 WMB, respectively.

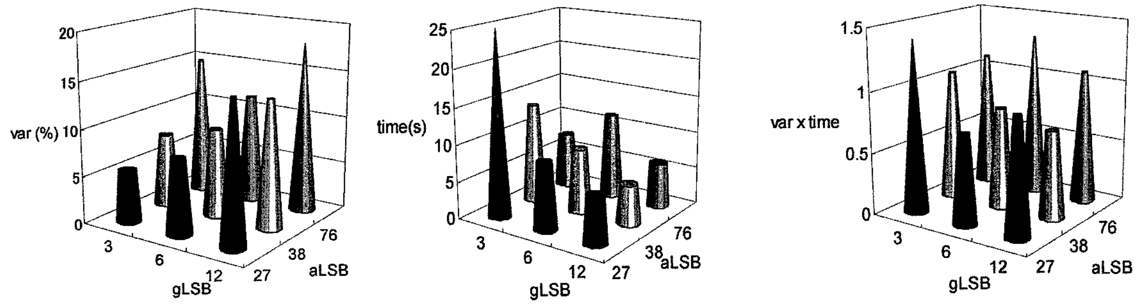
5. Measurement reliability among operators

The results of IM scores of Molteno-based models are given in Table 1. The variation was less than 12 % for a completely new operator (B). When the operator (A) become acquainted for a while, then the variation was decreased to 8.5 %.



(1) variation (2) measuring time (3) variation x measuring time

(a) axial direction



(1) variation (2) measuring time (3) variation x measuring time

(b) perpendicular direction

Fig. 9 Variation (var), a measuring time (time) and a variation x measuring time (var x time) in different measuring direction.

(a) regular-type implant model

direction	perpendicular				axial			
operator	A	B	C	D	A	B	C	D
IM score	72.0	72.6	72.6	76.9	86.5	92.0	98.8	94.2
SD	3.3	1.3	1.3	1.6	2.6	1.4	1.2	0.9
var (%)	4.5	1.8	1.8	2.1	3.0	1.5	1.2	0.9

(b) hard-type implant model

direction	perpendicular				axial			
operator	A	B	C	D	A	B	C	D
IM score	39.7	38.7	42.6	41.7	54.3	50.8	54.9	47.4
SD	3.3	4.3	1.8	0.8	4.1	1.2	1.0	0.9
var (%)	8.4	11.2	4.2	1.9	7.6	2.3	1.9	1.9

Table.1 IM scores result of regular and hard-type implant model measured by four operators.

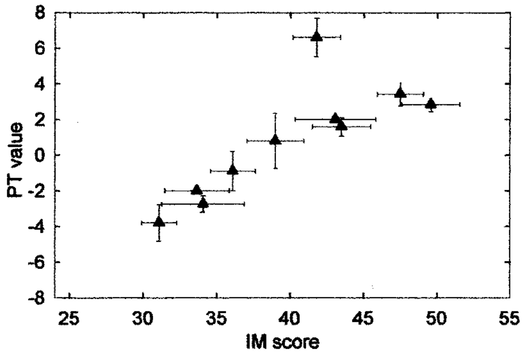


Fig. 10 The comparison between IM score and PT value.

However, for regularly used operator (C and D) of the device, the variation was as low as 2 %. This result was considered good, since all of the operators are not dentist or dental technician. The 12 % variation for a completely new operator was close to 10 %, which could be accepted as maximum value of variation. Therefore, the reliability and reproducibility of the device to measure the implant mobility was quite good.

The IM checker could also significantly discriminate the two models with statistical value of $P < 0.01$. There was no significant difference to measure the model at a certain direction of measurement among operators ($P < 0.01$).

6. Comparison to Periotest

The comparison result of the mobility measurement of dental implant models measured using Periotest and IM checker is given in Fig. 10. There was some similarity measurement result. However, variation of measurement of all model were 25 % using Periotest, while for the IM checker was 5 %. The higher measurement variation of the Periotest was known, as it was not designed for implant mobility measurement. As it was reported, the Periotest was not sensitive enough for assessing mobility of dental implant[9]. It was shown that the IM checker was better than the Periotest in term of less variation and the capability to measure implant mobility in axial direction.

Conclusions

The microcontroller-based implant movement checker is a portable type device, which can be easily put on dental chair side. It is very useful for clinical diagnosis because the implant mobility is obtained objectively and quantitatively. It could estimate small values of implant mobility and discriminate the mobility of dental implant models, which were estimated as M0. Moreover, it had a sufficient measuring reproducibility, reliability and sufficient measuring time. It is concluded that the IM checker had possibility to be applied in dental clinics for assessing implant mobility measurement. It is also found that Rigolac material was appropriate to make dental implant models as standard for assessing implant mobility measurement.

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マイクロコントローラを組み込んだ歯科インプラント動揺測定装置の開発

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要　　約

本研究の目的は歯科インプラントの動揺を簡易に測定できる装置の開発である。本装置では測定プローブで一定振幅の周波数を歯科インプラントに与え、その加速度信号を検出する。そして本研究で考察した評価基準に基づいてＩＭ値を表示する。さらにRigolac®やMolteno®を用い、インプラント体の長さおよび直径を変えたインプラントモデルを作製した。400Ｈｚにおけるモデルの機械モビリティとＩＭ値との間には、よい相関が見られた($R^2=0.92$)。ＩＭチェッカーを用い、一人の測定者が行った12回の測定において、インプラントの動揺を判別することが可能であった($P<0.01$)。また４人の測定者による測定では，その平均値に対し測定者間の有意差は見られなかった($P<0.01$)。従ってＩＭチェッカーは十分な信頼性を有し、歯科臨床に有効であると考える。

キーワード：歯の動揺、機械モビリティ、インプラント、触診

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