Assessment of Dental Implantation Osseointegration Through Electromagnetic Actuation and Detection[1]

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1 Background

Titanium-made dental implants have been proven an effective treatment for both completely and partially edentulous patients in the past two decades [1,2]. The surgery may fail if prosthesis is treated erroneously in placement, or loaded inappropriately. Bone loss and yielding defects usually reduce implant stability and eventually cause surgery to fail. The overall issues show the importance of assessment during the osseointegration; especially, the indication to single out the portion of structure instability helps dentists remedy such a situation. Many developed techniques and devices have been proposed to assess interfacial osseointegration and quantify bone defects [3–5]. Compared with invasive methods like removal torque analysis, noninvasive ways are considered more practical in clinics; for instance, the techniques through radiographic observation [1,3], static inspection [4], and dynamic detection [5–7] were proposed before. Recently, the resonant frequency analysis and associate device belonging to dynamic detection [5,7,8] have been extensively applied in dental osseointegration assessment, and also considered as a useful clinical tool due to its potentially noncontact detection nature.

Though the varied detection devices were developed in the past two decades, it is, so far, still in great demand on the techniques and devices to effectively differentiate irregular dental osseointegration and bone defects in a certain portion of implant/tissue-bone. To this end, this technical brief proposes and implements a one-piece electromagnetic (EM) driven device for the assessment of osseointegration for post dental implantation.

2 Methods

In this technical brief, an EM actuating and sensing mechanism as shown in Fig. 1(*a*) is explored; more precisely, an electromagnet and dual Hall-effect sensors (named hereafter as EM device) are employed for resonant frequency measurement. A driven electromagnet generates magnetic force to vibrate a permanent magnet attached to the detected structure. One of the dual Hall-effect sensors X is used to capture the oscillating excitation force, and the other one Y between the vibrating magnet and the electromagnet is to sense the varying magnetic field corresponding to vibration response. This design enables making a miniature and hand-held device possible due to actuation and detection both belonging to EM mechanism. The system transfer function $H(s)$, Fig. 1(*b*), is computed to characterize structure response rather than only using vibration response. Figure 2 shows the system block diagram of the EM device, including actuation and detection parts, LABVIEW graphic user interface (GUI), and a power amplifier. The dual linear Hall-effect sensors are fastened back-to-back and attached on an electromagnet (or an EM coil), which makes the EM device in a single device. Besides, four 1.5 V rechargeable batteries in a battery holder power, the detection device uses a regulator IC 7805 to stabilize voltage supply for dual Hall-effect sensors at 5 V. Figure 3 shows the GUI coded by LABVIEW for EM measurement. Through the interface, the frequency response function $Y(\omega)/X(\omega)$ characterizes the resonant

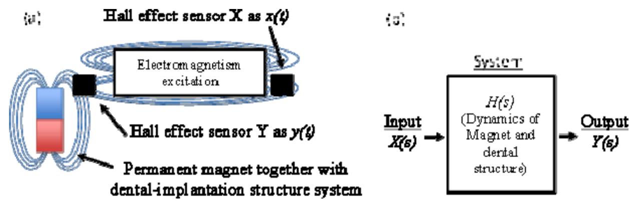

Fig. 1 Illustration of EM device for measuring dental-implantation structure resonance; (*a*) schematic of EM excitation and Hall-effect sensing and (*b*) transfer function of *Y*(*s*) to *X*(*s*) characterizing structure resonance

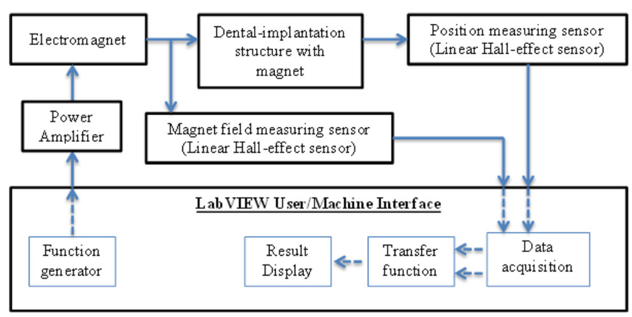

Fig. 2 Block diagram of EM actuating and sensing device

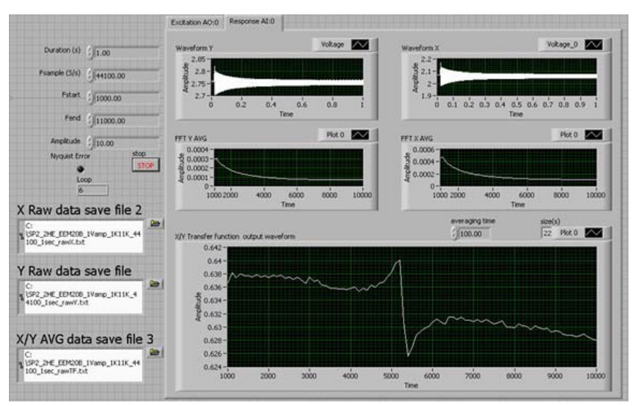

Fig. 3 LABVIEW user/machine interface designed for EM measuring device

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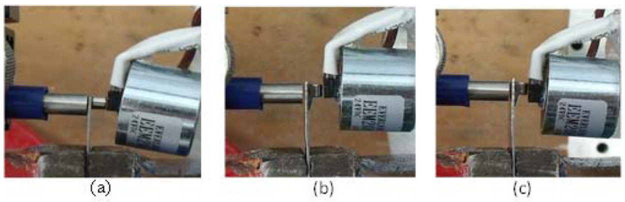

Fig. 4 Measurement of a cantilever structure using the proposed EM device with a trial of (*a*) head-on, (*b*) upper side-by, and (*c*) lower side-by measurement. At the left-hand side of each photo a capacity displacement sensor is used to acquire vibration response for comparison.

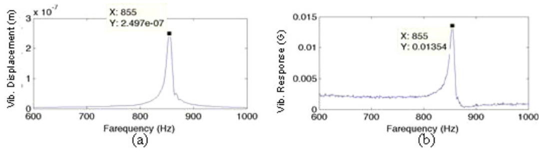

Fig. 5 Frequency response through head-on measurement using (*a*) capacity displacement sensor and (*b*) Hall-effect sensor

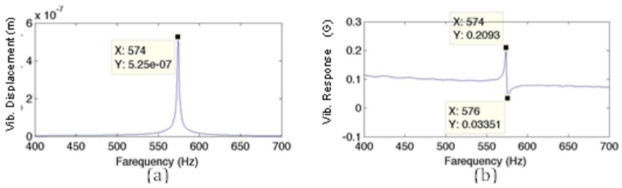

Fig. 6 Frequency response through upper side-by measurement using (a) capacity displacement sensor and (b) Hall-effect sensor

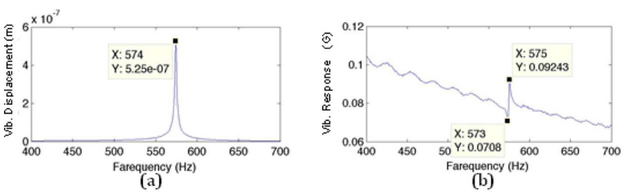

Fig. 7 Frequency response through lower side-by measurement using (a) capacity displacement sensor and (b) Hall-effect sensor

peaks of structure. In the in vitro or in vivo tests, the control interface enables a user to set measuring duration, sampling frequency, and frequency range and amplitude scale of swept sinusoids. Moreover, the loop structure to acquire measurement is designated, and is stopped by a stop button. The captured data strings are saved under the user defined path.

For using the proposed EM device, three measuring conditions, including head-on, and both upper and lower side-by, were attempted, as shown in Figs. 4(*a*)–4(*c*), respectively. Here, the "head-on" and "side-by" mean one pole of a magnet attached on the structure, and the magnet attached on the structure by side, respectively. The trial measurement setup is equipped with an iron rule like a cantilever structure, firmly fixed by a vise jig. In each photo, the right-hand side part is the prototype device, where an electromagnet is attached by two back-to-back Hall-effect sensors. Moreover, a capacitive-type displacement pickup is set up on the opposite side of the ruler to capture the vibration response for comparison.

Fig. 8 Photo of measurement setup using prototype EM device in the axial direction of rabbit tibia to monitor the osseointegration of implantation

Table 1 Measured (anti)resonant frequency (Hz) for the first 8 weeks after dental implantation ($P<0.01$, $P<0.01$*; $R^2=0.97$, $R^2=0.96$*)

Week 0	Week 2	Week 4	Week 6	Week 8
3869 ± 53	3298 ± 26	4934 ± 55	5831 ± 65	5037 ± 57
4130 ± 53*	3538 ± 24*	5317 ± 90*	6287 ± 6*	5359 ± 6*

3 Results

The measurement of simple cantilever structure using prototype device with three varied conditions shows the results in the part (*b*) of Figs. 5–7; the part (*a*) of each figure results from the measurement by the displacement sensor. It is observed the head-on measurement shows one peak for each resonance, and the side-by measurement (upper or lower) shows a pair of peak and valley. The side-by measured spectra characterize both (anti)resonance peaks due to the interaction of magnetic flux of Hall-effect sensor with the dipole of the magnet, whereas the Hall-effect sensor approaching and detecting the monopole of the magnet results in no antiresonance.

The proposed noncontact EM device has been employed in a preliminary animal test. Figure 8 shows the measurement in the axial direction of rabbit tibia, where a dental implant was inserted for monitoring the healing progress. Table 1 lists the measured (anti) resonant frequencies for the first 8 weeks after dental implantation. It clearly shows that the implant structure resonant frequency first decreases after primary osseointegration, and then increases along the healing.

4 Interpretation

The EM device shows feasibility of measuring structural resonance. The preliminary in vivo test characterizes the healing progress with frequency first dropping off and then going up, which reflects and is consistent with the healing progress.

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