DETERMINATION OF TOTAL HIP ARTHROPLASTY STEM STABILITY BY INTRAOPERATIVE MEASUREMENT USING AN ACOUSTIC TESTING TECHNIQUE

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Introduction: The lack of initial post-operative implant stability is recognized as an important determinant in the aseptic loosening process of cementless stem. However, there is no objective method to evaluate the mechanical stability at the time of implantation. In our previous study, it is confirmed that our system could successfully provide a criterion of the appropriate size of the rasp by measuring the acoustic energy(1). This study presents the intraoperative protocol derived from the previous in vitro study and the results of intraoperative measurements using an acoustic testing technique.

Materials and Methods: The experimental apparatus consists of a custom microphone and a data acquisition system. The custom microphone is a bone contact microphone (Yamaha Corps, QQ1YSK001107). The data acquisition system consists of a portable microphone amplifier (Audio-Technica Inc., AT-MA2), a USB oscilloscope (Pico Technology, ADC-210/100) and a computer. A clinical evaluation was conducted during THA. A volunteer patient (a 73-year-old man with OA) was included in this study after informed consent and approval by the institutional review board. The femoral head of the femur was removed and the smallest rasp (#4) was inserted. Once the rasp seated at the neck level, the microphone was attached(Fig.1).

Fig. 1 a view of the microphone during surgery.

The rasp was impacted by the impactor and the impact sound was received by the microphone. The received sound signal was amplified, digitized by the oscilloscope and obtained by the computer. The rasp size was increased stepwise until the size determined at preoperative planning has been achieved(#8) and the same measurements were taken three times for each separate rasp size.

Results: In this experiment, it is found that the impact sound from rasps can be expressed as the following equation.

\[ V(t) = \alpha_0(\alpha_1 \cos(2\pi f(L)t - \phi_1) + \alpha_2 \cos(2\pi f(H)t - \phi_2)) \exp(-\kappa t) \]

In this equation, t is time, V is the signal of the impact sound, f(L) is the lower resonant frequency, f(H) is the higher resonant frequency, \( \phi_1 \) is the phase of the lower resonance, \( \phi_2 \) is the phase of the higher resonance, \( \kappa \) is the dumping factor, and \( \alpha_0 - \alpha_2 \) are fitting constants. We evaluated the contact condition by using f(L), f(H) and \( \kappa \) in the equation. The spectrums of the impact sound have two resonant peaks. The lower resonant frequency is about 1.9 kHz and the higher resonant frequency is about 2.2 kHz (Fig.2).

In the equation, the parameter \( \alpha_1 \) shows the magnitude of the lower resonance and \( \alpha_2 \) shows that of the higher resonance. Figure 3 shows the magnitude ratio between these two resonance (\( \alpha_1/\alpha_2 \)). The magnitude ratio from #8 rasp was clearly larger than that from others.

Discussion: The two resonant frequency observed in impact sounds were constant values in all obtained data. Thus, the origins of these resonance was the mechanical characteristics of rasps and femur. The higher frequency resonance related to the mechanical resonance of the rasps and the lower frequency resonance related to that of femur. The impact by a impactor induced resonant vibration in both rasp and femur. When the contact condition was loose, the transmissions of the impact (from the rasp to the femur) and the vibration sound of femur (from the femur to the rasp) were small, respectively. Larger rasps improved the contact condition and the transmission of both the impact and the vibration sound. By improving the contact condition the magnitude of the signal from the femur was increasing and that from the rasp was decreasing. It would cause the large change of the magnitude ratio of the two resonance. In conclusion, the results imply that the proposed system could determine the possibility of the precise stem size intraoperatively.