THE ADVANCEMENT OF COMPLETE HIP ARTHROPLASTY SUPPORT SYSTEMS: THE SELECTION OF HAMMERING SOUND COLLECTING DEVICES

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Abstract

By listening carefully to the hammering noises made by the stem being placed into the femur during total hip arthroplasty, intraoperative femoral fractures can be prevented. This method is based on a hammering test that takes use of the fact that sound depends on an object's stability. Typically, engineering uses this method. A system based on this method and software for real-time spectra analysis has been created with continual advancements in order to prevent excessive stem hammering by forecasting the intraoperative fracture risk. The final technical hurdle is choosing a suitable sound gathering tool and creating a small, simple machine. In order to create a useful THA support system, this study examined the kinds of directional microphones appropriate for the sound gathering system. The peak frequencies of the hammering noises were collected and compared using four different types of microphones based on chosen methodologies, and clinical trials were then carried out using the developed system. Plug-in unidirectional microphones are suitable for the unit's compactness and simplicity of use. Nevertheless, no laboratory-level data have been gathered, thus more data gathering is required.

Keywords: Peak Frequency, Fourier Analysis, Hammering Sound, Intraoperative Fractures, Complete Hip Arthroplasty

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1. Initialization

Total hip arthroplasty (THA) is a surgical technique to replace an inoperable hip joint with a hip prosthesis. Recent advancements in hip arthroplasty have sought to enhance results and lessen side effects (Zhuang et al., 2022). Nevertheless, it has been noted that between 0.4% and 4.9% of significant intraoperative fractures occur during surgery (Mihalko et al., 2014).
The lack of a criteria for determining if the stem is adequately stable is one of the reasons of intraoperative femoral fracture (Moroni et al., 2000). Surgery is now performed based only on the surgeon's intuition and expertise rather than any objective evidence. Insufficient stability is the result of an inadequately fixed stem. Because intraoperative fracture results from a stem that has been too fixed to promote stability, it is feasible to prevent intraoperative fracture by appropriately fixing the stem during surgery on the basis of scientific evidence (see Figure 1).
Research to date suggests that it is feasible to prevent intraoperative fracture by listening for hammering noises coming from the stem being fixed into the femur, keeping in mind that the sound relies on the object's stability (Schwartz Jr et al., 1989). Software for quick Fourier analysis has been developed with continuous advancements, and a system has been created to prevent intraoperative fractures (Carroll & Clark, 2006). The final technical difficulty is to choose a suitable sound gathering tool and construct a small, user-friendly gadget.
The following three criteria, particularly those connected with the choice of sound gathering technologies, were the main focus of this study in order to create a workable THA support system. The best directional microphones for a sound gathering system were first examined. The peak frequencies of the hammering noises were then collected, compared, and compared between using four different types of microphones based on the chosen methodologies. Ultimately, clinical trials were carried out using the built-in system.

2. Materials and Methods

Choosing microphones

A dual-channel sensor amplifier (SR-2200 from Ono Sokki, Japan), a digital storage scope (DSO-2250 USB from Hantek Electronic Co. Ltd., China), and a laptop computer make up the THA support system for avoiding intraoperative fractures (Endeavor NJ1000 from Epson, Japan). The electret-condenser, dynamic, and DC-biased condenser types were compared in order to choose the best directional microphone to be used in this support system. The microphones' kinds, output levels, noise levels, sensitivity levels, and sound characteristics are listed in Table 1.

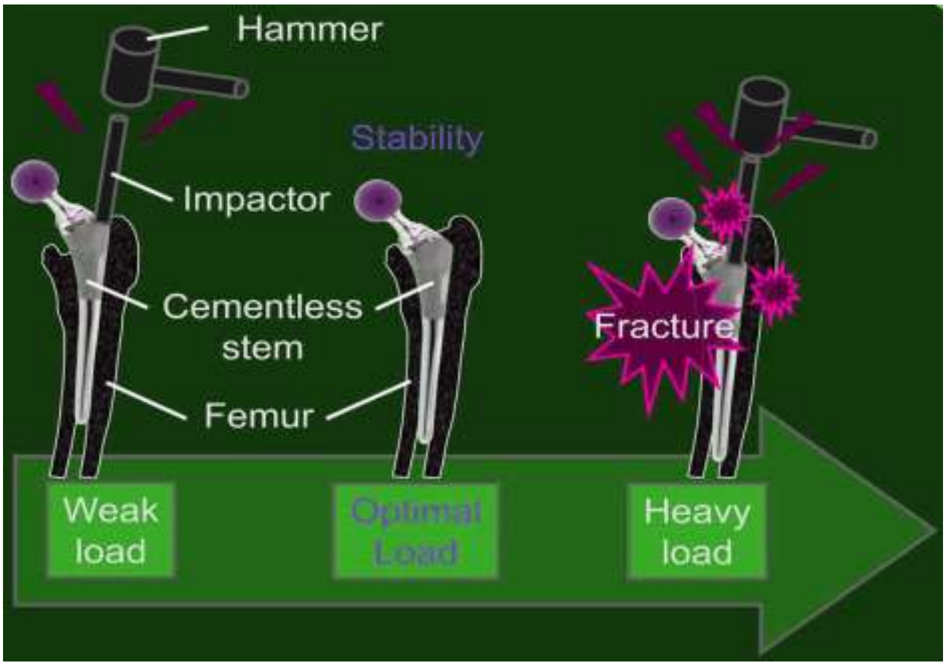


Figure 1: The stem will get looser if the amount of force or strikes is insufficient. Fractures occur during surgery when the stem is struck too frequently.

Table 1: Sound quality, output, noise, sensitivity, and kind of microphones

Type	Output	Noise	Sensitivity	Sound quality
Electret condenser type	Normal	Normal	Normal	Versatile and delicate. Compared to the DC bias type, it cannot pick up minute level sound.
Dynamic type	Low	Normal	Low	Suitable for high volume recording
DC bias capacitor type	High	Low	High	Delicate and smooth. Abundant information at a minute level.

To collect hammering sounds under the same circumstances, the THA support system was equipped with four different types of dynamic and DC-biased condenser directional microphones: Type A (F-P5500 from Sony, Japan), Type B (BETA58A from Shure Inc., IL, USA), Type C (C391 from Harman International Japan Co. Ltd., CT, USA), and Type D (BP4073 from Audio-Technica Corporation, Japan). Dynamic microphones of Types A and B and DC-biased condenser mics of Types C and D are available. The directivities and frequency responses of microphones are listed in Table 2.

Systems (VerSys from Zimmer, USA) were implanted into mannequin femurs in the lab (Sawbones Medium Left Femur 1121-19: Pacific Research Laboratory, WA, USA). The systems were repaired with the surgical tools utilised in the clinical trials using the same technique as the THA utilising a hammer (VerSys from Zimmer, USA) through an inserter (VerSys from Zimmer, USA). The mimicked femurs were positioned about a metre distant from directional microphones. Each microphone was constructed using six fictitious femurs. The peak frequencies at which the amplitudes were maximum were determined by short-time Fourier transformations using an FFT analyzer (DS-3000, Onosokki, Japan).

Clinical trials

The ethical committee of the organisation to which the author belongs authorised this work (B16-239). At Kitasato University Hospital, from June to December 2017, clinical studies were carried out on 12 joints in 12 cases of complete hip replacements (for four male patients and eight female patients, with a mean age of 70.1 years old). An orthopaedic surgeon with more than 20 years of clinical experience who specialises in the hip joint conducted the procedure.

The system needed to be a portable, user-friendly piece of technology that could be brought into operating rooms. In order to create an application, Microsoft Visual C# 2010 was utilised as the programming language and Microsoft Visual Studio 2010 as the development environment. The programme often runs on a Windows-powered tablet Computer called the PC Miix 2 8 (from Lenovo Company, China) (OS).

The THA support system's hardware and software were modified, and as a result, microphones were chosen once more. The handheld unidirectional microphone F-P5500 from Sony, Japan, which performed the best in the testing, was compared to microphones E (i266 from MI Seven Japan Inc., Japan), a plug-in unidirectional cordless microphone, and microphone F, a plug-in super-directive small microphone (AT9913 from Audio-Technica Corporation, Japan) (Table 3). One microphone and the system were utilised to assess each case, with the microphones being situated 2 m distant from the surgical field. Four out of the 12 instances received a microphone at random. The directivities and frequency responses of the microphones are listed in Table 3.

3. Results and Discussion

Peak frequencies for the four directional microphone types A, B, C, and D were, respectively, 0.70 0.03 kHz, 0.30 0.09 kHz, 0.72 0.01 kHz, and 0.67 0.05 kHz. In contrast to the other microphones, microphone A showed its peak frequency clearly (Figure 2(A)). Compared to the peak frequencies of the other mics, Microphone B's peak frequency was more than 1 kHz lower (see Figure 2(B)). While Microphone C's peak frequencies—the most important data—showed a smooth waveform, they were dispersed (Figure 2(C)). Low-frequency noises were captured by microphones B and D (Figure 2(D)).

Table 2: Features of the laboratory microphones that were utilised

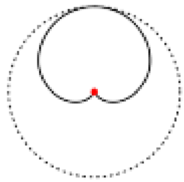
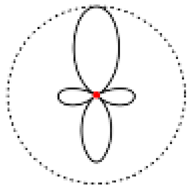
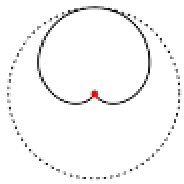
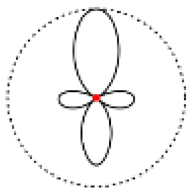
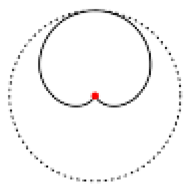
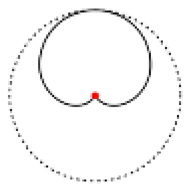
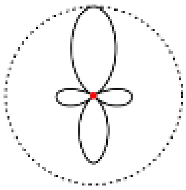
Type	Product	Directivity	Frequency characteristics
Dynamic type	A	Unidirectional 	50 Hz - 20 kHz
	B	Super directional 	50 Hz - 16 kHz
DC bias capacitor type	C	Unidirectional 	20 Hz - 20 kHz
	D	Super directional 	20 Hz - 20 kHz

Table 3: characteristics of the operating room microphones

Type	Product	Directivity	Frequency characteristics
Dynamic	A	Unidirectional type 	50 Hz - 20 kHz
Plug in type	E	Unidirectional 	20 Hz - 20 kHz

F	Super directional		70 Hz - 15 kHz

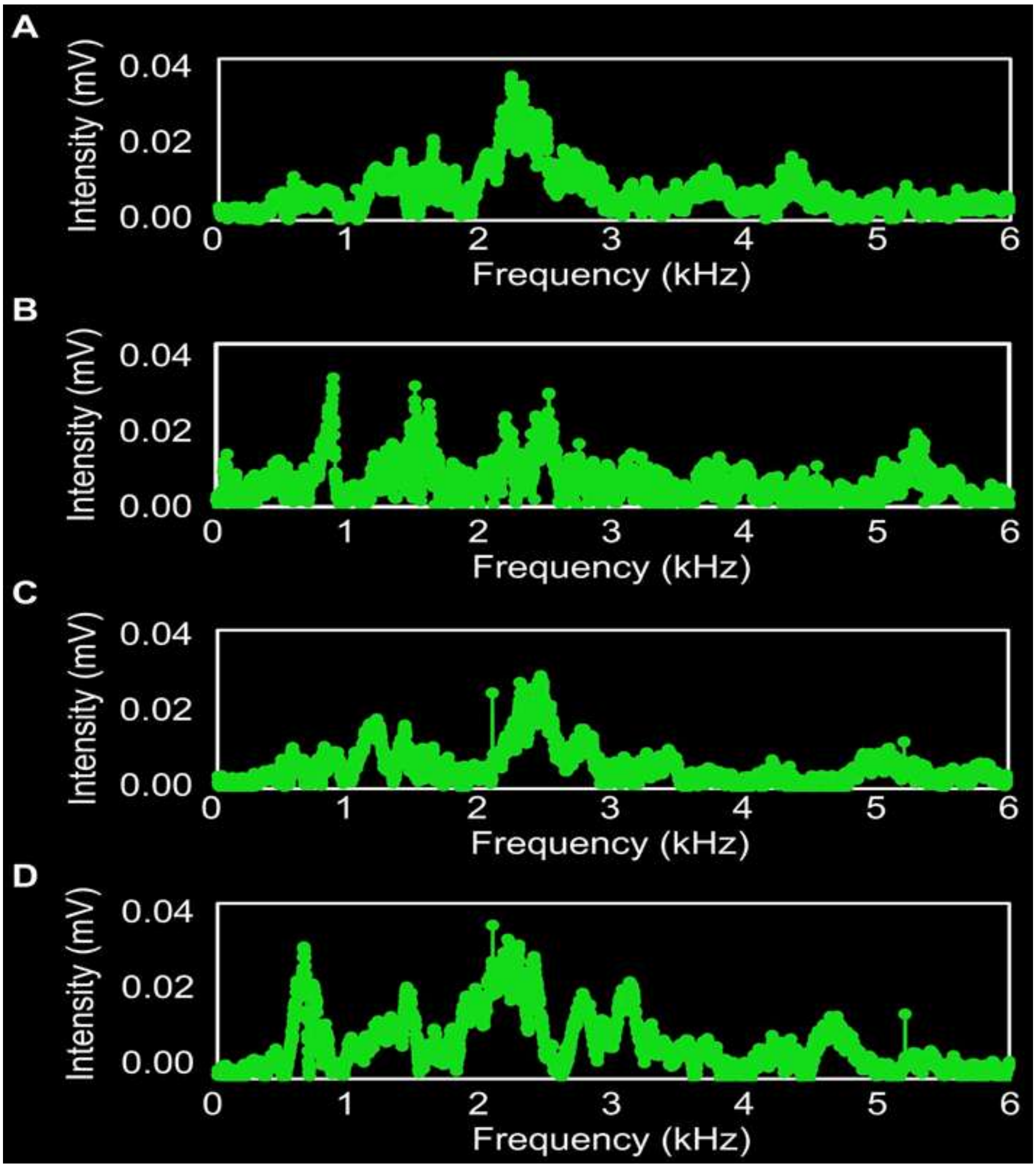


Figure 2: Both the frequency and the volume of each microphone. (A) Microphone A had an exceptional peak. (B) The peak frequency of microphone B was at least one kHz lower than that of the other microphones. (C) Microphone C's peak frequency changed. (D) Microphone D had the ability to pick up information at low frequencies.

In one of the four situations in the clinical trials, microphone A was unable to pick up a single pounding sound. Out of a sequence of 58 hammering noises recorded by microphone A, one was incorrectly counted, as shown by the undetected data in Figure 3(A). In certain instances, Microphone B was successful in picking up any hammering sounds. All instances of Microphone C's failure to pick up hammering noises resulted in 4 3.16 counting mistakes. Five counting mistakes were found out of 96 hammerings in one of the four situations when microphone C was utilised, as shown in Figure 3(B).

4. Discussion

The hammer and inserter's recognisable frequencies make up the hammering sound's frequency components (Carroll & Clark, 2006). According to (Sakai et al., 2011), the frequency components of the hammering sound are essentially independent of the hammer and inserter manufacturers. We stated that the peak frequency is around 3 kHz (Sakai et al., 2020) based on earlier studies. A peak frequency was present in Microphone A that was somewhat close to this number and did not disperse much. Dynamic microphones can capture a lot of sound and are reasonably priced (Sakai et al., 2013). We think that because dynamic microphones are user-friendly and can withstand hard handling in clinical settings, they are appropriate for bone fracture prevention devices.

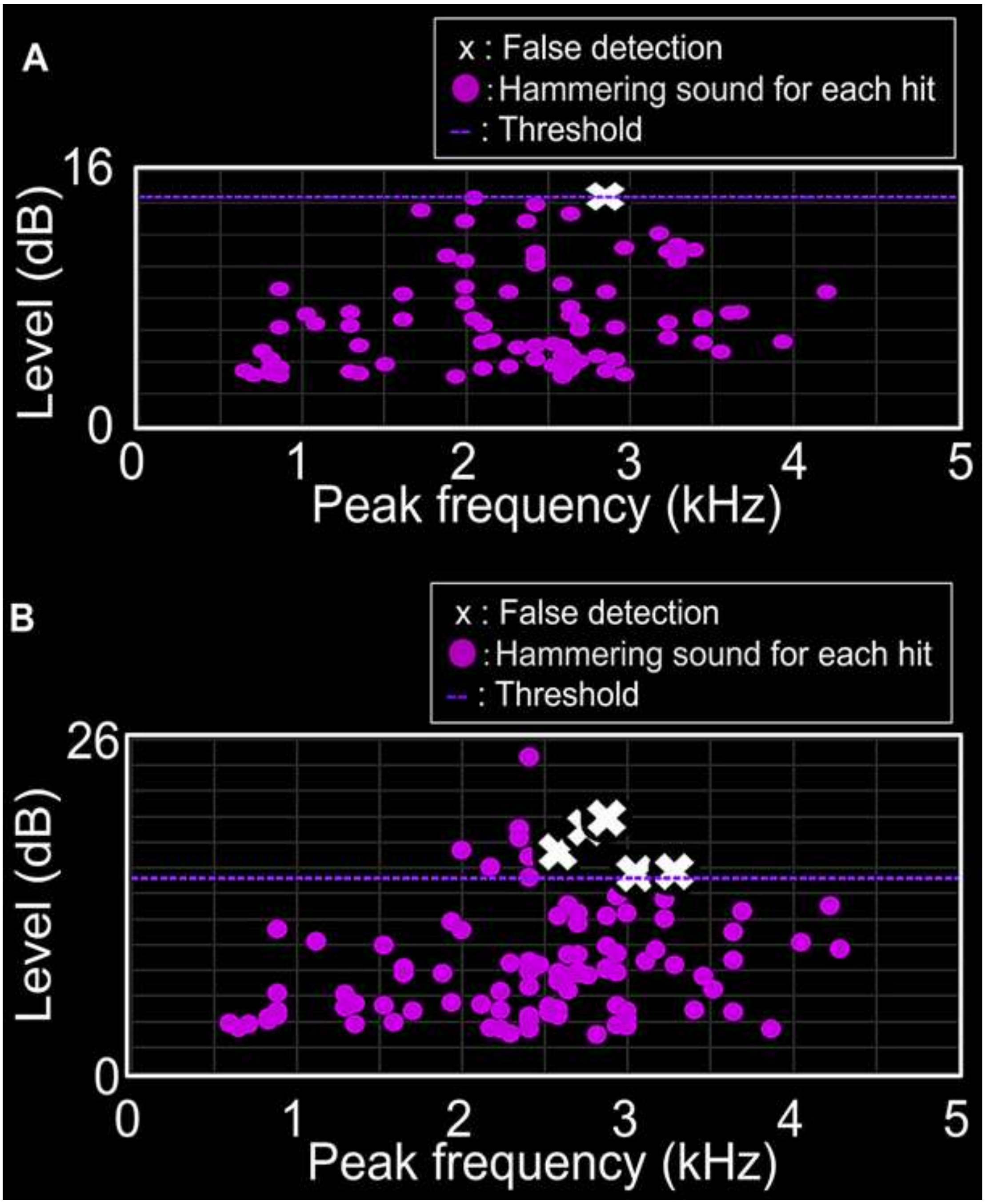


Figure 3: Level and peak frequency of each microphone. The hammering sound is depicted on the orange plot, while the undiscovered data is displayed on the x plot. (A) Of the 58 instances of hammering recorded by microphone A, there is one counting mistake. (B) After hitting microphone C 96 times, there were 5 count mistakes, which prevented the data from being identified.

While being inexpensive enough for sound recording, dynamic microphones have drawbacks due to their poor output and sensitivity levels (Sakai et al., 2011, 2020). Condensers that were

DC-biased showed significant levels of output and sensitivity. Nonetheless, they are expensive, precise optical tools that need to be handled with care (for example, exposure to high temperatures and humidity must be avoided). For these reasons, we think they are unacceptable for use in operating rooms as gadgets. DC-biased condensers are great at gathering low-pitched noises and may gather a lot of micro-information. Hammering noises, on the other hand, are high-pitched and not delicate, therefore a DC-biased condenser microphone is not necessary (Sakai et al., 2021). Electret condenser microphones provide high-quality audio because they have an electrical circuit and batteries. Nevertheless, because batteries are usually stored inside of electret condenser microphones, they have drawbacks that might result in battery leakage and are hence not recommended (Sakai et al., 2013).

We believed that the microphone should be smaller in size since it must be taken into operating rooms, despite the fact that the laboratory investigation showed that Microphone A, a portable unidirectional type, functioned effectively. The frequency responses of microphones A, E, and F, which are plug-in unidirectional, portable unidirectional, and plug-in super directive types, respectively, cover the frequency range of the pounding sound. As the microphone cannot be positioned close to the surgical field, which is the source of the sound, we anticipated that the super directive type would be effective for gathering noises. The results, however, demonstrated the superiority of the unidirectional variants. We discovered that unidirectional types gathered sound across a larger area than super directive types, and as a result, they were able to capture noises coming from the operator, the barrier, and the sound source (Sakai et al., 2013).

We decided that microphone E was suitable because compactness was the first need for the sound gathering equipment. To preserve statistics, however, the data volume must be raised because it is insufficient. Since ossein varies during clinical studies, it is challenging to manage the qualitative data that is gathered (Whitwell et al., 2013). As a result, new laboratory-level data was gathered. It may be decided that Microphone A, a dynamic handheld unidirectional type, or the plug-in unidirectional microphone, is suitable as a sound collecting device for the THA support system if the microphone is not expected to produce many false detections.(Xie & Ling, 2012) As a restriction, we thought the microphone's construction had no bearing on the outcomes. We have not determined if gender and age are different in the information gathered(Pederson et al., 1998).

5. Conclusion

The standards for judging if the stem is adequately stable must be covered. Analyzing the hammering sound made by the stem being placed into the femur is one method for preventing intraoperative fractures. Based on this approach, a method to reduce intraoperative fracture risk was created, and software for real-time analysis was created with ongoing THA support system enhancements. The technological problem that remains is choosing a suitable sound gathering tool. This study established the suitability of dynamic handheld unidirectional microphones for sound recording. Plug-in unidirectional microphones are discovered to be suitable for the downsizing and operating simplicity of the THA support system. With plug-in unidirectional microphones, no laboratory-level data have been gathered, hence more data must be acquired in the future.

6. References

Carroll, M. H., & Clark, M. D. (2006). Men's acquaintance rape scripts: A comparison between a regional university and a military academy. Sex Roles, 55(7), 469–480.

Mihalko, W. M., Wimmer, M. A., Pacione, C. A., Laurent, M. P., Murphy, R. F., & Rider, C. (2014). How have alternative bearings and modularity affected revision rates in total hip arthroplasty? Clinical Orthopaedics and Related Research®, 472(12), 3747–3758.

Moroni, A., Faldini, C., Piras, F., & Giannini, S. (2000). Risk factors for intraoperative femoral fractures during total hip replacement. Annales Chirurgiae et Gynaecologiae, 89(2), 113–118.

Pederson, M., Olthuis, W., & Bergveld, P. (1998). High-performance condenser microphone with fully integrated CMOS amplifier and DC-DC voltage converter. Journal of Microelectromechanical Systems, 7(4), 387–394.

Sakai, R., Kikuchi, A., Morita, T., Takahira, N., Uchiyama, K., Yamamoto, T., Moriya, M., Uchida, K., Fukushima, K., & Tanaka, K. (2011). Hammering sound frequency analysis and prevention of intraoperative periprosthetic fractures during total hip arthroplasty. Hip International, 21(6), 718–723.

Sakai, R., Takahira, N., Uchiyama, K., Yamamoto, T., Fukushima, K., Tanaka, K., Uchijima, D., Itoman, M., & Mabuchi, K. (2013). Usefulness of Hammering Sound Frequency Analysis as an Objective Evaluation Method for the Prevention of Fractures During Total Hip Arthroplasty. Orthopaedic Proceedings, 95(SUPP_15), 247.

Sakai, R., Uchiyama, K., Fukushima, K., Takahira, N., Yoshida, K., & Ujihira, M. (2021). Hammering sound frequency analysis to fix an acetabular cup during total hip arthroplasty: clinical trials and biomechanical studies. Journal of Biomedical Science and Engineering, 14(1), 14–20.

Sakai, R., Yamamoto, T., Uchiyama, K., Fukushima, K., Takahira, N., Yoshida, K., & Ujihira, M. (2020). Prediction of Intraoperative Fracture by Hammering Sound Frequency Analysis and Stress Estimation during Total Hip Arthroplasty. Journal of Biomedical Science and Engineering, 13(6), 113–119.

Schwartz Jr, J. T., Mayer, J. G., & Engh, C. A. (1989). Femoral fracture during non-cemented total hip arthroplasty. The Journal of Bone and Joint Surgery. American Volume, 71(8), 1135–1142.

Whitwell, G., Brockett, C. L., Young, S., Stone, M., & Stewart, T. D. (2013). Spectral analysis of the sound produced during femoral broaching and implant insertion in uncemented total hip arthroplasty. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 227(2), 175–180.

Xie, J., & Ling, S.-F. (2012). A method of measuring acoustic absorption coefficient of a material specimen using a dynamic microphone. Journal of Mechanical Science and Technology, 26(3), 741–748.

Zhuang, X., Homma, Y., Ishii, S., Shirogane, Y., Tanabe, H., Baba, T., Kaneko, K., Sato, T., & Ishijima, M. (2022). Acoustic characteristics of broaching procedure for post-operative stem subsidence in cementless total hip arthroplasty. International Orthopaedics, 46(4), 741–748