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Determination of The Hip Stem Loosening Using Vibration Method

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Abstract

Aseptic loosening is a common problem in total hip replacement surgery. Routine radiological imaging techniques are used for postoperative diagnosis. The alternative technique is required to develop because of the low success rate in current diagnostic techniques. The purpose of this study is to develop the new method to diagnose the aseptic loosening of the stem using vibration technique. Two different experimental setups were established in this study, vibrational and cyclic loading tests. In the vibrational test, the bone-prosthetic models were vibrated from the distal femur at a certain frequency and then the vibration data were taken via accelerometer from the trochanter region of the femur. The vibration data were converted to the frequency domain for evaluations. The stability of the femur-prosthesis system was determined by evaluating the fundamental frequency change and harmonics generated at the FFT analysis. In the cyclic loading test, the femur-prosthesis system was forced to fatigue at a maximum amplitude of 1700 N and 1 Hz frequency. After every 5000 cycles in the test, the femoral prosthesis system was connected to the vibrational test and the loosening of the system was considered. After 115000 cycles, the harmonic frequencies were observed and the amplitude value of the fundamental frequency was decreased. The experiments were stopped when the stem was pulled out easily from the femur. As the degree of the loosening increased, the number of the harmonics increased and the fundamental frequency values decreased. In conclusion, the vibration method can be used as an alternative technique to determine the degree of the hip stem loosening.

Key words

Aseptic loosening, Total Hip Prosthesis, Vibration Technique, Cyclic Loading

1. INTRODUCTION

Orthopedic prostheses are frequently used for treatment in orthopedic surgery. The most common problem in the prostheses is aseptic loosening especially in hip prosthesis [1]. Because of this problem the prostheses dislocate and become unfunction. Hence, the revision surgery which is more difficult and costly is required.

An average of more than 1.2 million Total hip prosthesis (THP) surgeries are performed around the world and %10 of these surgeries are revised with the reason of the aseptic loosening [2]. The number of THP surgeries may estimate to increase with the long life expectancy through the developing technology and treatment opportunities. The radiology imaging methods are used for the detection of the loosening and the success of this method is very low [3].

In this study, the vibration method was evaluated to detect the loosening degree of THP. Two different test techniques have been established, the vibration and cyclic loading tests. The bone-prosthetic models were vibrated at a certain frequency and amplitude then the response of the bone-prosthetic system was evaluated in vibration test. In the cyclic loading test, the femoral prosthesis model was forced to be fatigue by cyclic loading. The harmonic frequency and amplitude changes were evaluated the loosening degree of the bone-prosthesis system.

2. MATERIALS AND METHODS

Fourth generation composite sawbone femur model (Sawbone Europe AB, Malmö, Sweden) and the pelvis model (Keklikoglu plastic Industry, Kayseri, Turkey) was used. Cementless Echelon stem and cup (stem length 160 mm, cup diameter 50 mm) was implanted in the femur and pelvis models. A metal stem head with a diameter of 26 mm was used together corresponding polyethylene inlay.

2.1. Vibration Test Method

The femur-stem-pelvis models were placed onto a test apparatus as seen in Figure 1. The pelvis model was fixated at three locations onto the sigma-profile. Rubber dampers were placed between the junctions of the test components. Four tension springs were used to stabilize the femur and pelvis joint. Two upper springs were simulated the gluteus medius muscle and two below springs were simulated the adductors magnus and longus (Figure 1). The springs were attached with the cords.

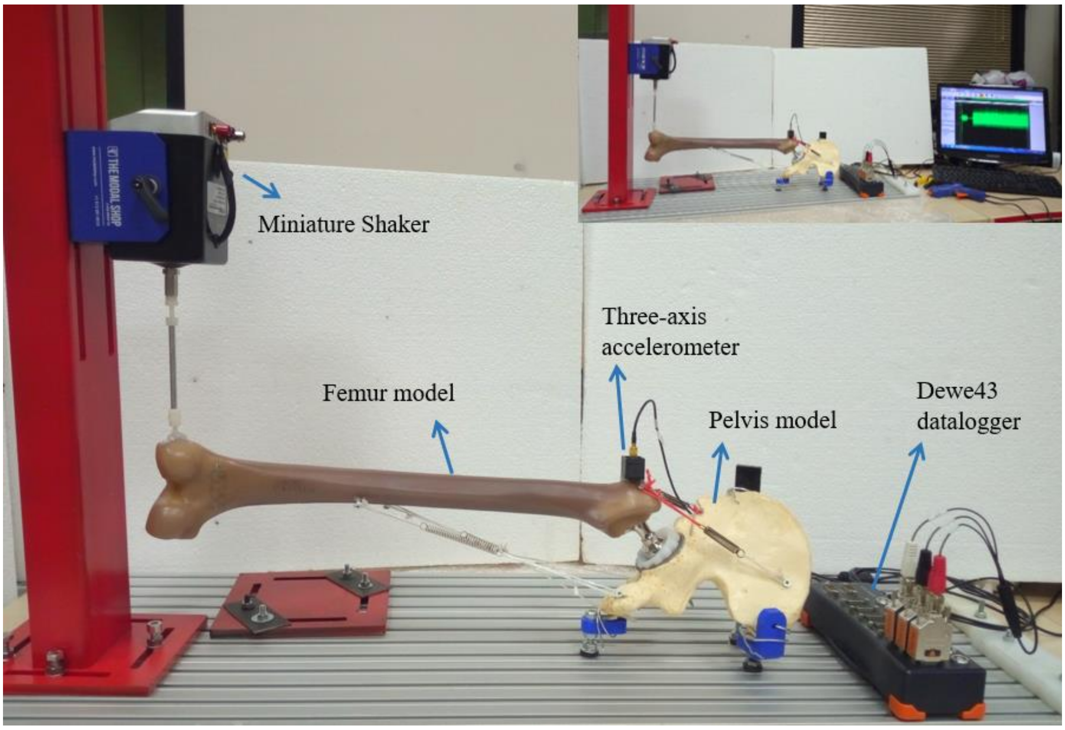

Figure 1. Vibration test setup

The femur-pelvis system were vibrated at the 200 and 250 Hz frequency via miniature shaker (The Modal Shop, Cincinnati, OH, USA) at the distal femur. Three-axis accelerometer (Measurement Specialties, Marmatek, Turkey) was placed at the greater trochanter of the femur. The vibration data were collected for ten seconds using DEWE43 datalogger (Dewesoft, Kumberg, Austria). 10 kHz low pass and 10 Hz high pass filters were used to prevent the noise. It was also used 50 Hz block filter to prevent the electric network noise. The vibration data were evaluated by performing Fast Fourier Transform (FFT) analysis. The occurrence of the harmonic frequency in the vibration data received from the system is an indication of the deterioration of the system integrity. In addition, the changing of the amplitude of the vibration data were evaluated in stabilized and unstable systems.

2.2. Cyclic Loading Test Method

In cyclic loading test, the femoral prosthesis model was forced to be fatigue by cyclic loading in universal test machine as seen Fig. 2. Distal femur was fixed with the clamps. The cyclic loads between 100 N and 1700 N in 1 Hz were applied on the stem head. The purpose of the cyclic loading is to damage the contact between the femur model and stem by simulating the real condition. Thus, the degree of the loosening and the deterioration of the connection between the femur and the stem can have been determined.

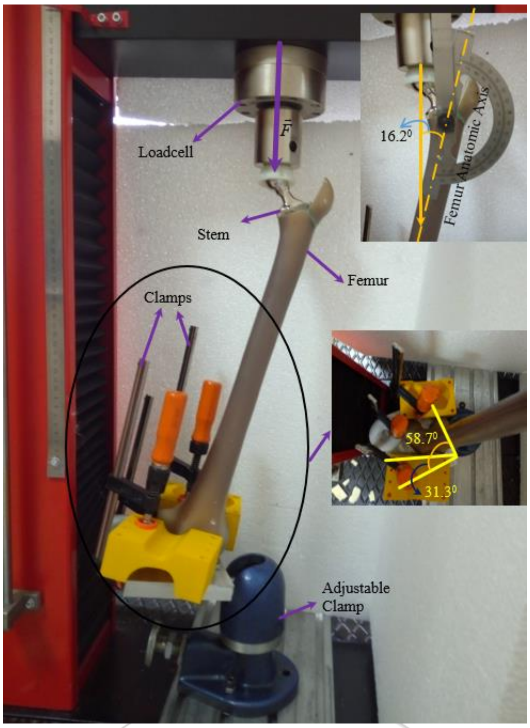

Figure 2. Cyclic loading test

3. RESULTS AND DISCUSSION

The stable femur-stem system was vibrated at 200 and 250 Hz to determine the stable system data. These data were the reference data to examine the loosening situations. The system was then applied the cyclic test to loosen the system. In 115000 loading cycle, the vibration data changed. The harmonic frequencies were observed and the amplitude of the main frequency was decreased. After each loading tests were applied in 5000 cycle loading, the vibration tests were executed. The stem completely loosened in the 125000 loading cycle. The graphs of stable and unstable systems were given in Fig. 3 and 4. The unstable system has three harmonic frequencies. Also, the amplitude of the main frequency in unstable system decreased with respect to the stable system.

The differences between the graphs provide important information about the system stability. The number of the harmonic frequencies indicate the contact status between the femur and stem. As long as the integrity of the system was distorted, the number of harmonics increased. The magnitude of the main frequency in the unstable system was lower in the stable one. Hence, this change in the magnitude of the main frequency is the indication of the system stability. The results of the stable and unstable systems were given in Table 1. The scoring system can be improved by these results and the stability of the system can be shown on the numerical value.

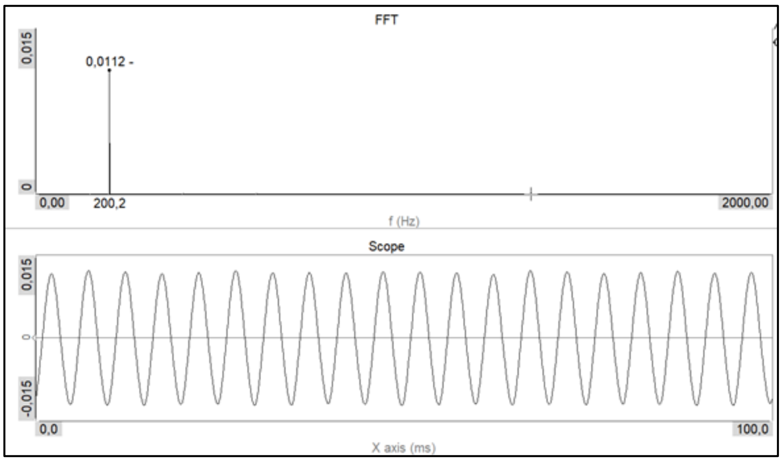

Figure 3. The amplitude-time graph and its FFT form in stable femur-stem system vibrating in 200 Hz frequency

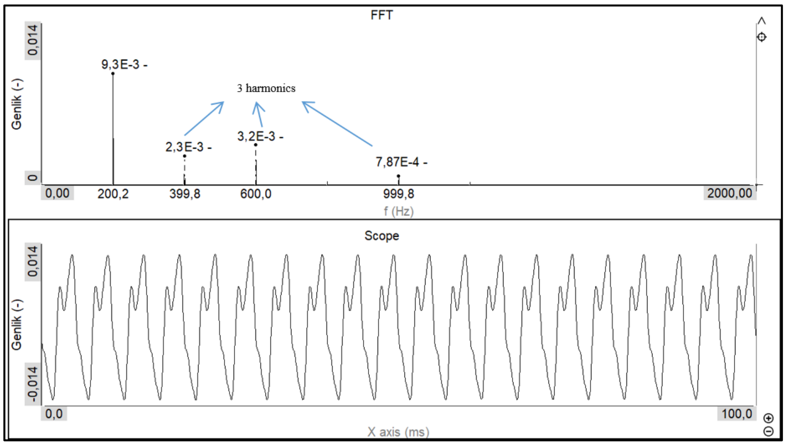

Figure 4. The amplitude-time graph and its FFT form in loosened femur-stem system vibrating in 200 Hz frequency

Table 1. The results of the stable and loosened femur-stem systems

	The magnitude of the main frequency (10^{-3})		**The number of the harmonic frequency**	
The number of the cyclic loading	200 Hz	250 Hz	200 Hz	250 Hz
Stable system	11.2	7.35	-	-
115000	11	7.25	1	2
120000	10	6.86	2	2
125000	9.3	6.39	3	3

Aseptic loosening of the hip stem is a major problem. The studies about the THP loosening were studied that the system is loose or stable [3-5]. In this study, the degree of the loosening was evaluated and it was shown the scoring system could be developed. Thus, the vibration method can be used as an alternative method in post-operative patient follow-up and the state of hip prosthesis stability can be determined.

The vibration method has been emphasized to be reliable and minimally invasive in many studies [3-6]. For this reason, it is a method that can be developed as an alternative to the currently used radiological imaging method with the low-success rate in determining aseptic loosening.

Rieger et al. [5] used the methods of counting peak amplitudes together with resonance frequency analysis to determine prosthesis stability. This method provides information about whether the system is loose or stable, but post-operative patient follow-up cannot be performed. Because the resonance frequency also depends on the mechanical properties of the parts that constitutive the system. Postoperative mechanical properties of human bone may change with reference to preoperative bone properties.

4. CONCLUSIONS

In conclusion, the vibration method can be used as an alternative method for determining the aseptic loosening of the hip prosthesis and the determination of the degree of the loosening. Besides, the prosthesis stability can be more useful with the numerical value that the scoring system will be developed.

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