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ANALYZING EXPERIMENTAL SYSTEM FOR HIP PROSTHESIS EXPOSED TO VIBRATION

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Abstract: *This paper contains the description of a test system for a hip prosthetic through vibration analysis. Long-term success of the THR and TKR is affected by a high rate of erosion of the prosthesis, several years after surgery. One reason for this is the changing transfer of the load, which often cause bone erosion at the interface between the femur and artificial joint. Optimizing implant design and its mechanical behaviour can reduce this effect. Also testing the vibration frequency of the different parts of the bone and prosthesis it could be determined the frequency of unwanted vibration source.*
Key words: *Hip prosthesis, vibration, accelerometer, THR, cement.*

1. INTRODUCTION

Primary arthroplasty of the hip is a highly successful operation that provides joint mobility and maintain normal physiological functioning over long periods (15-20 years).

Failure of total hip arthroplasty (THA) is the ratio between the patient and physician expectations on the one hand, and technological limitations, on the other hand. As a surgical reoperation is necessary only in case of a failure, it is needed to distinguish between damage of the implant or a component and technology limitations.

Advances in the development of biomaterials and design of the prosthesis, could lead to increased life of implants and decrease the incidence of aseptic loosening and other complications [1]. Total hip replacement (THR) is one of the most successful operations worldwide [2]. Loosening of the implants evolves from micro motion between the bone and cement. Mobilization hip prosthesis may occur at the interface bone cement or cement-prosthesis interface or from the damaged cement mantle. Besides loosening there are different other problems that concern THR. These are: polyethylene insert wear, late infection, recurrent instability – luxation, damage of prosthetic components etc.

Loosening of the femoral component is one of the primary contributors to failure of cemented total hip replacements. In these procedures polymethylmethacrylate (PMMA) bone cement is introduced within the femoral canal to achieve load transfer between the metal implant and the femoral bone. Previous research has identified that loosening of cemented implants under cyclic loading is largely attributed to fatigue and the progressive accumulation of damage within the bone and cement at the bone/cement interface [3]. While both mechanical and biological factors have important contributions to the progression of loosening, the underlying mechanisms are still not clear [3]. The quality of mechanical interlock between the cement and bone and the corresponding resistance to fatigue degradation are critical elements to long-term survival.

2. RESEARCH STAGES

Detection of loosening or assessment of Osseo integration of orthopaedic implants, particularly of total hip replacement (THR) components, remains a challenge. For several years conventional imaging based techniques have been used (plain film radiography, digital subtracted arthrography, Roentgen stereo photogrammetric analysis, scintigraphy), but the diagnostic sensitivity and specificity are not entirely satisfactory [4]. This paper details a diagnostic technique by vibration analysis, in vitro, for monitoring the internal condition of the hip prosthesis implanted in the femur by means of a suitable processing of the measured vibration signal.

In order to achieve femur-prosthesis system it was used a prosthesis implanted into a human cadaver femur. Considering only the structure of the bone the differences between the fresh and used one aren't very important. Also we consider performing the same tests on fresh bone and on similar models as well. The studies were taken on a single femur with multiple tests.

In this paper was used acrylic bone cement CEMFIX-1 produced by TEKNIMED S.A. - Biomateriaux-Implants Orthopediques, France.

CEMFIX-1 is used to secure the prosthesis to the bone during surgery as a result of trauma or other infections, as well as during the operation of the review previous arthroplasty.

CEMFIX-1 has a standard viscosity, self-stabilizes quickly hardens minimize settling time and can be applied manually.

The maximum temperature of 70°C reached during polymerisation of CEMFIX 1 cement is well below the requirements of standard ISO 5833, so reducing the risks of bone necrosis. The mechanical properties of CEMFIX 1 cement are significantly better than the requirements of standard ISO 5833 in flexion, compression and intrusion.

A limited number of experiments prove the feasibility of detecting several forms of loosening with vibration analysis, in vitro as well as in vivo [5]. In these experiments a vibration is applied to the femur in the medio-lateral plane with frequencies up to 1000-1200 Hz. "Late loose" hip stems can be distinguished well from securely fixed stems and for this specific purpose, the method can be used clinically in the frequency range below 1000 Hz. However, to detect "early loosening" or to monitor Osseo integration in an early stage, the method as it was originally developed seems to have insufficient diagnostic sensitivity [4].

A well-fixed bone-implant system behaves as a linear dynamic system when subjected to mechanical excitation. When a severe loosening has occurred, the composite structure behaves as a non-linear system and distortions can be observed in the response signal when a harmonic excitation is applied. During the early stage of loosening of an implant, however, the structure bone-implant still behaves in a good approximation of a linear system and a harmonic distortion-based method will have a low sensitivity [5].

The distal end of the femur is placed on the vibration source, model 394C06, and the other end is suspended on a metal stand.

Femur-prosthesis system will be induced a series of vibrations from the vibration source model 394C06 (figure 1). Femur-prosthesis system response will be captured in the first phase by a triaxial accelerometer model 356A16 ICP (figure 2.a), which will be placed in five different points of the femur and by using the HVM100-L1, the results will be sent to a computer and interpreted (figure 1).

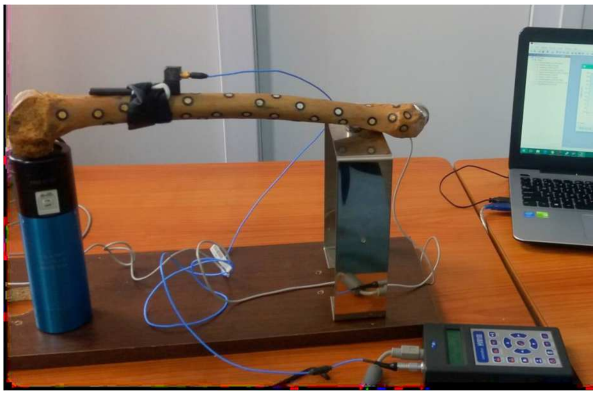


Fig. 1. The test system of the prosthesis of the hip. The first method of measurement.

PCB Piezotronics triaxle accelerometer has the following characteristics:
- High Sensitivity
- Ceramic coating ICP® Accel.,
- 100 mV / g,
- 0.5 to 5K Hz,
- Measuring range: ± 50 g pk (± 490 m/s² pk)
- Resolution broadband (1 to 10,000 Hz) 0.0001 g rms (0.001 m / s² RMS)
- Frequency range (± 5%) (y or z) 0.5-5000 Hz.

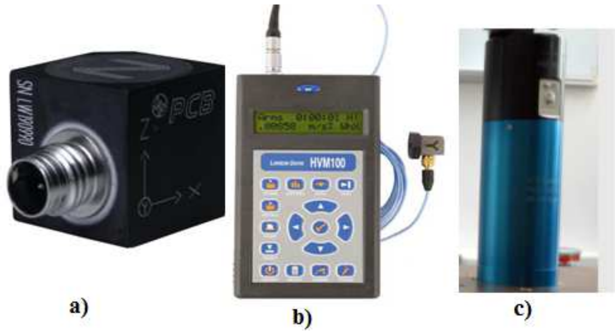


Fig.2. a)-ICP accelerometer Triaxle model 356A16; **b)**- HVM100-L1 device; **c)**- HVM vibration source, model 394C06.

HVM 100 is a small but powerful digital tool for measuring vibration (figure 2.b). This portable vibration analyser will allow variety of applications, including whole-body vibration analysis, vibration analysis and hand-arm vibration overall analysis.

This vibration analyser has three input channels, a channel sum, a variety of weights and frequency settings for limiting bandwidth, simple integration and double data displayed in a variety of units, output AC or DC independent for all 3 channels simultaneously.

HVM vibration source, model 394C06 (figure 2.c), is a portable device which is small, handy, and a source of vibration completely self-contained. The 394C06 model allows precise adjustment of the measuring equipment to indicate a level of standard acceleration of RMS or peak of 1 g.

3. METHODS

Identifying how the vibrations are transmitted into the body of the prosthesis, and the bone, it can conduct to CAD design allowing the use of optimal proportions between the material and its structure and also the importance of cement in the fixation of prosthesis. Before starting the test, ICP accelerometer is calibrated on 3 axes. Calibration is performed using vibration source on which ICP triaxle accelerometer is placed on each of the three axes. After calibrating the accelerometer, vibration source is used to excite the femur-prosthesis system. The measurements are taken in five different points. The system response is recorded separately as an acceleration signal in different locations, according to figure 3. This response is a harmonic function of a certain amplitude.

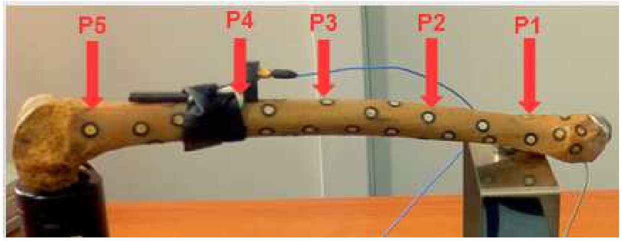


Fig.3. Five different points of accelerometer placement.

It was used Blaze software to display the data.

The accelerometer is fixed with a screw adapter to HVM100 system, which is then fixed with a Velcro strip to prevent lateral movements.

4. RESULTS

The measurement results were as follows:

In P1 (right):

Value	Channel X	Channel Y	Channel Z	Sum	Units
Aeq	.70900	3.8600	4.8400	6.2100	m/s²
Amax	.78200	4.3100	5.1100	6.6000	m/s²
Amp	1.8000	7.3000	8.1100	9.8300	m/s²
Amin	.01020	.01240	.00645	.01760	m/s²

In P2 (right)-figure 4.a:

Value	Channel X	Channel Y	Channel Z	Sum	Units
Aeq	1.7100	3.0200	3.9900	5.2800	m/s²
Amax	3.9400	5.5500	7.2400	9.5400	m/s²
Amp	Over	Over	Over	Over	m/s²
Amin	.00416	.00410	.00327	.00669	m/s²

In P3 (middle)- figure 4.b:

Value	Channel X	Channel Y	Channel Z	Sum	Units
Aeq	5.6600	7.5000	5.9000	11.100	m/s²
Amax	7.0100	9.1700	7.2700	13.600	m/s²
Amp	Over	Over	Over	Over	m/s²
Amin	.00392	.00349	.00384	.00648	m/s²

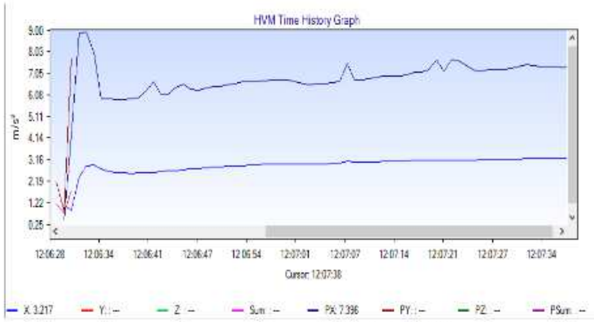
In P4 (left):

Value	Channel X	Channel Y	Channel Z	Sum	Units
Aeq	1.9300	4.7600	5.3600	7.4100	m/s²
Amax	1.9800	5.0700	6.0400	7.6600	m/s²
Amp	6.1700	Over	Over	Over	m/s²
Amin	1.7900	4.2500	5.1100	7.2700	m/s²

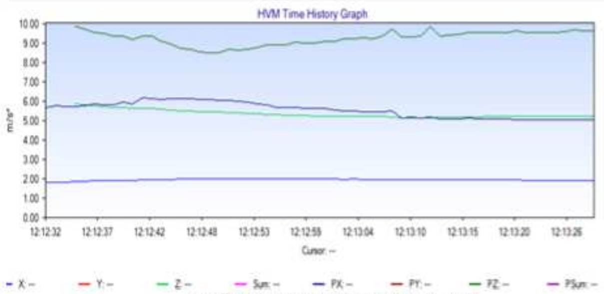
In P5 (left):

Value	Channel X	Channel Y	Channel Z	Sum	Units
Aeq	6.6600	8.7500	7.5400	13.300	m/s²
Amax	6.8400	9.1100	7.6400	13.700	m/s²
Amp	Over	Over	Over	Over	m/s²
Amin	4.3900	5.8100	5.1800	8.9200	m/s²

It is noted that the maximum amplitude increased from 0.78 m/s2, in P1, to the value of 6.84 m/s2 in P5. So we can say that the vibration amplitude decreased when the accelerometer was positioned at a distance from the vibration source.



a) measurement results in P2



b) measurement results in P3

Fig.4. Some of the results obtained in P2 and P3 points.

5. CONCLUSIONS

By studying the vibration modes of the human femur and of selected THR prosthetic stems, two conclusions can be formulated: 1- the differences between the vibrational behaviour of an intact femur and of the system formed by a femur and an implanted prosthesis will increase with increasing complexity of the mode shapes of the system; 2- when a prosthesis is implanted in a femur, the vibration modes of the prosthesis will be more affected by this interaction than the modes of the femur. Vibration modes of the femur bone can influence the fixation of the prosthesis in the bone. Various fixations might get different results through this vibrational analysis due to the material of the prosthesis and also due the interaction between the prosthesis and the bone. The results obtained in this study conduct to the conclusion that the fresh cemented prosthesis offer a very good fixation of the prosthesis in the femur, not allowing to generate amplified vibrations in the bone.

As future directions a system for testing prosthetic hip through vibration analysis for hip prosthesis uncemented to observe amplitude changes in comparison to the cemented prosthesis, and applying this analysis in vivo in individuals who have implanted a hip prosthesis.

6. REFERENCES

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Sistem experimental de analiza a protezei de sold expusa la vibratii

Rezumat: Lucrarea conține descrierea unui sistem de testare pentru o proteză de șold prin analiza vibrațiilor. Succesul pe termen lung al THR și TKR este afectat de o rată ridicată de eroziune a protezei, după operație. Un motiv pentru aceasta este transferul diferit al sarcinii, care adesea cauzeaza eroziuni osoase la interfața dintre femur și articulația artificială. Optimizarea design-ului la implant și a comportamentului său mecanic poate reduce acest efect. De asemenea, testarea frecvenței de vibrație a diferitelor părți ale osului și protezei ar putea determina frecvența sursei de vibrații nedorite.

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