Mechanical Vibration - A quick and Efficient Method of Removing Damaged Prosthesis from its Cemented Position

Ahmed M. Kadoura
Cape Peninsula University Of Technology
/Department of Mechanical Engineering
Cape Town, South Africa
Ahmed.gadura@yahoo.com

Jasson Gryzagoridis
Cape Peninsula University Of Technology
/Department of Mechanical Engineering
Cape Town, South Africa
GryzagoridisJ@cput.ac.za

Abstract—**Implant replacement or revision surgery in the human body ranks among the most demanding surgeries that orthopedic surgeons encounter in modern medicine.**

The removal of the hardened bone cement which secures the implant within the bone, is the cause of a lengthy operation. Often the use of sharp surgical instruments, ultrasonic devices etc. are employed, however all these methods are time-consuming and present various complications.

This paper describes the use of mechanical vibrations at a frequency of 40 Hz, on samples of implants anchored in animal (pig) bone cavities with bone cement. Using a rotary hammer drill equipped with a specially designed adaptor, to engage the tip of the implant, good results were obtained. The implant with its cement mantle was removed in a short time not exceeding 22 seconds.

The procedure appears to be safe and is accomplished in a short time, commensurate with what is required in revision surgery.

Index Terms: **Bone cement, vibration, Orthopedic, ultrasonic, Implant.**

I. INTRODUCTION

The scientific development in orthopedic surgery has led to the search for alternatives to damaged parts of the human body such as bone and joints (knee joint, hip-joint…etc).

Manufactured medical devices normally known as implants may be employed to support a damaged bone or replace a damaged joint.

Bone cement is a substance used in fixing solid implants and artificial joints at the inner surface or hollow space of the bone in humans [1] and acts as a mechanical link that helps to increase the transfer of load between the bone and the implant [2].

There are cases where well-fixed cemented components need to be removed due to various reasons such as those listed as follows: infection [3], painful condition, polyethylene wear, implant/bone geometrical mismatch, malposition with chronic dislocation and removing distal cement plugs [4].

Received 14 Jul, 2019; revised 21 Aug, 2019; accepted 21 Aug, 2019.

Available online Aug 22, 2019.

Many challenges face the orthopedic surgeon when there is a need to remove an implant cemented in bone (in order to replace the damaged implant), a procedure known as revision surgery.

In other words how to separate an implant from its cemented position and cement from the cavity of a bone, in a safe and easy way.

Bone cement that holds metal implants into the cavity of a bone in the human skeleton is too strong to break up easily, therefore procedures are needed that will not involve collateral damage and prolonged anesthesia time, not to mention the physiological response of the patient and surgeon’s exhaustion. How can it be done without damage [5]?

II. DESIGN AND EXPERIMNTS

The early experiments that investigated the effect of heat, ultrasonic waves, and mechanical vibrations,were conducted on samples where bone cement was used to secure real implants within the cavities of bones from animals (pigs). The results from the heating of bone cement and the use of ultrasonic waves were not satisfactory and will not be dealt in detail here. However, mechanical vibration generated with a laboratory Vibration Generator when applied to the samples, did produce some promising results as is as summarized in Table I. It is depicted that there was no effect when the sample was exposed for 15minutes at each frequency, but when the sample was exposed for a lengthier time (reached 60 minutes) a positive effect was observed. A crack appeared in the bone cement and the ‘implant’ could easily be removed or separated from the bone cement.

Table 1. The Effect of Frequency of Mechanical Vibration and Time of its Application Using a Laboratory Vibration Generator

Freq	Time	WAVE	Effect	notes
30(Hz)	15 min	Square	NO	No cracks
50(Hz)	15 min	Square	NO	No cracks
80(Hz)	15 min	Square	NO	No cracks
80(Hz)	60 min	Square	yes	Cracks at bone cement+ implant separation

Subsequent experiments with the use of a rotary hammer drill, equipped with the component that was designed and developed to transmit the vibrations to the cemented implant, yielded the desired results. The schematic diagram in Figure1 together with the following narrative, serves to summarize the physics of the application of force/vibration and how to handle/secure the sample so that the force/vibration on it, would have the desired effect of separating the cement mass containing the implant, from the 'bone's cavity'. With such a result there would be no further onerous task for the surgeon of having to remove cement from the bone cavity.

- It was desired to hold the sample tightly in a balanced manner by the source of vibration and apply an axial tension on the implant.
- Arrange that the reaction to the applied tensile force on the implant is felt directly on the sample's edge/end surface of the bone.
- The frequency of the vibration was gradually changed during the experiments in order to establish the effective range for the desired
- separation of the component

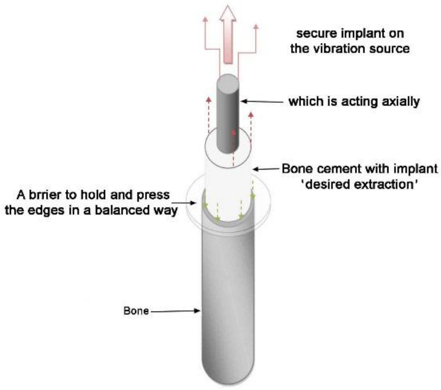

Figure 1. The Physics of Applying a Mechanical Vibration to the Sample

Figure 2 represents a schematic of the whole experimental assembly or set-up i.e. the vibration source (Rotary Hammer Drill), the mechanism of transmitting the vibration to the sample, and the holding of the sample.

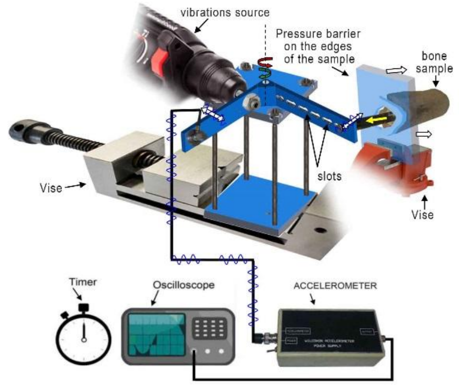

Figure 2. The Schematic of the Experimental Set-Up

The apparatus or set-up used in the final experiments as seen in Figure 2 above, has a central component which may be called 'vibration connector', which enables connecting or transmitting the vibration from the source to the head of the implant. It is fashioned after the classical 'bel crank' mechanism where mechanical advantage can easily be accomplished. In this case the different slots at distances away from the pivotal point (c) accomplish mechanical advantage in addition to the directional change (90 degrees) of the force/vibration applied. Figure 3 is a detail drawing of the 'vibration connector'.

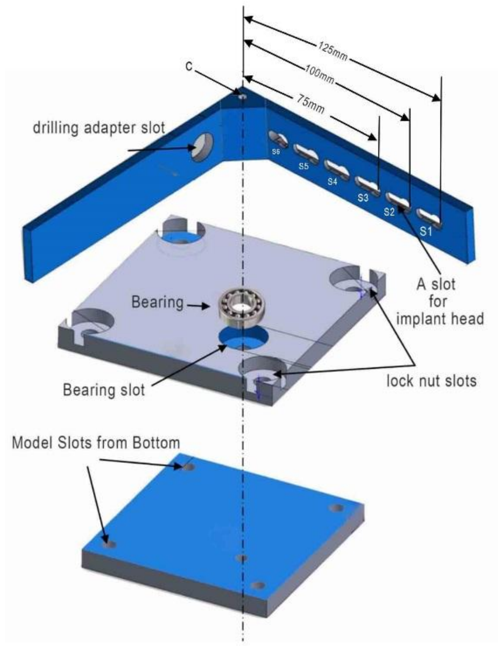

Figure 3. Detailed Drawing or Features of the 'Vibration Connector'

The various experiments that were performed with numerous samples, aimed at determining the best frequency generated by the vibration source, the best distance between pivot and implant's head, and the time that it took for completing the procedure of ideal implant extraction from the bone cavity.

III. RESULTS

Table 2 shows the summary of the results from a group of experiments that were performed in order to establish as mentioned above, the best distance between the implant's head and pivot point (75 mm), and the vibration of 40 Hz being more effective than other frequencies (10, 20, 30) Hz, in that the implant was removed with the mass of cement together (i.e. ideally) at the shortest time….around 20 sec.

Figure 4 is a photographic record of the 'ideal' implant extraction from three different types or geometrical configurations of animal (pig) bone.

TABLE 2. Positive Results after optimizing the 'pivotal distance' and vibrational frequency applied on the samples

no	Freq	Time	Distance c.....to.....s	Effect on the sample
Sample 1	40 Hz	22 sec	75 mm	The implant with cement removed as one mass
Sample 2	40 Hz	19 sec	75 mm	↓
Sample 3	40 Hz	20 sec	75 mm	↓

Figure 4. Positive results with pig bones encasing the cement and implant positioned at optimum pivotal distance and exposed to optimal frequency of vibration.

CONCLUSION

At the beginning of the study, or during the early experiments, the aim was to obtain acceptable results by using heat and/or ultrasonic waves in an attempt to melt or loosen the bone cement.

However, the preliminary experiments that were carried out by heating the samples confirmed what was reported in the literature by previous studies [6,7]. Only high temperatures can soften bone cement, and when dealing with the human body, it would cause burns or damage to tissue or bones.

The findings of this study suggest that mechanical vibration can be used to remove the implant and bone cement from a bone cavity. The procedure appears to be safe and is accomplished in a short time, commensurate with what is required in the replacement of joints in revision surgical operations.

REFERENCES

[1] M. Vert *et al*., '*Terminology for biorelated polymers and applications (IUPAC Recommendations 2012)*', *Pure Appl. Chem.*, vol. 84, no. 2, p. 1, 2012.

[2] R. M. Guedes, M. Gomes, and J. A. Simões, '*DMTA analysis for long-term mechanical behaviour prediction of PMMA-based bone cements*', *J. Biomater. Sci. Polym. Ed.*, vol. 17, no. 10, pp. 1173–1189, 2006.

[3] P. N. Smith and K. S. Eyres, '*Safe removal of massive intrapelvic cement using ultrasonic instruments'*, *J. Arthroplasty*, vol. 14, no. 2, pp. 235–238, 1999.

[4] R. Gardiner, W. J. Hozack, C. Nelson, and E. M. Keating, '*Revision total hip arthroplasty using ultrasonically driven tools: a clinical evaluation*', *J. Arthroplasty,* vol. 8, no. 5, pp. 517–521, 1993.

[5] NICE, ' *The OSCAR 3 ultrasonic arthroplasty revision instrument for removing bone cement during prosthetic joint revision*,' November 19, pp. 1–22, 2014 https://www.nice.org.uk/advice/mib13 last visited 13 Jul 2019

[6] A. T. Brooks, C. Nelson, C. L. Stewart, R. A. Skinner, and M . L. Siems, ' *Effect of an ultrasonic device on temperatures generated in bone and on bone-cement structure*.', *J.Arthroplasty,* vol. 8, no. 4. pp. 413–418, 1993

[7] P. Postawa and A Szarek '*Analysis of changes in bone cement damping factor and its effect on bone load'*, vol 23, pp . 35–38, 2007