

A Powered Technique for Inserting Acetabular Cups

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Abstract. This work focused to investigate the use of a powered automatic technique to insert acetabular cup implants. The use of a percussion hammer tool as a surgical instrument to insert acetabular cup implants was investigated in current work. Pull-out, lever-out and torque tests were carried out on cup implants inserted into test block specimens of polyurethane (PU) using specifically designed experimental setups as a means of comparing the current mallet and cup introducer (manual impaction) technique against the percussion hammer tool (powered impaction) technique. The experimental tests were based on calculating the maximum forces or moments of forces required to remove the cup implants from a test block specimen, which was representative of the acetabulum of the pelvic bone. It was found, the cup implants inserted using the powered impaction technique required a greater applied force, moment of force and torque in order to remove the cup from the cavity of the PU block specimen in the pull-out, lever-out and torque tests respectively. In terms of stability, the percussion hammer tool has the potential to improve the seating of cup implants within the cavity using a more precise and controlled technique, thus improving the over stability of the inserted cup implant.

Keywords: Total hip replacement (THR), Acetabular Cup implants, powered insertion technique.

Introduction

Total hip replacement surgery (THR) is a surgical procedure whereby the bones which make up the hip joint are replaced with prosthetic implants. The stability of acetabular cup implants, as part of a total hip replacement (THR), is a major influencing factor in terms of the overall long term survivorship of the implant. The ability to achieve this initial stability is related to the characteristics of the cup implant, the surgical insertion technique used and the skill of the surgeon which involves striking a shell introducer instrument connected to a cup implant with several blows of a mallet until the implant is adjudged to be sufficiently stable. The largest factor in success or failure of these cementless hips is the Surgeon, and there is a significant learning curve in inserting them [1]. Following reaming of the acetabulum and the femoral shaft the acetabular cup and femoral stem implants are normally hammered into position using an orthopaedic hammer, which is somewhere between the weight of a carpenter's hammer and a stonemason's lump hammer. The approximate force would equate to driving a 3 inch carpenter's round nail with a flat head into the end grain of a block of white deal with 6-7 blows. In the USA, approximately 158,000 THRs are carried out on an annual basis, with an average of 32,000 of these total hip replacements being revision cases. A revision total hip replacement is whereby the implants inserted into a patient in a primary total hip replacement have had to be replaced due to failure and is considered to be a much

more difficult surgical procedure compared to primary THR [2]. Approximately half of all total hip replacement revisions are due to misalignment of the prosthetic implants, specifically, acetabular cup implant misalignment. The most probable cause for this misalignment is considered to be the surgical technique which is used to implant the acetabular cup [3].

The femur and pelvic bones forming the hip joints in the body can be divided into two main categories: (i) Cortical (compact) Bone and (ii) Trabecular (spongy) bone also known as cancellous Bone. Mechanical properties of bone can be found in Table 1 [4].

Table 1: Properties of natural bone [4]

Bone Type	Young's Modulus (GPa)	Compressive Strength (MPa)	Tensile Strength (MPa)	Shear Strength (MPa)	Density (g/cm ³)
Cortical Bone	4-27	30-160	45-175	50-70	18-22
Trabecular bone	1-11	7-180	-	-	1.5-1.9

Cortical bone is found on the outer surface of the bones and is dense in nature. In terms of the hip joint cortical bone forms the entire outer surface of the femoral bone and also makes up the rim and outer surface of the pelvic bone. The material used as the test specimens for experiments in this work was rigid polyurethane (PU) foam. PU foam is the most common material used in biomechanical testing as an alternative material for representing human cancellous bone. Although not possessing the same mechanical properties of natural cancellous bone, PU foam provides a uniform and consistent test material and its properties are in the range of human cancellous bone [5]. The properties of the two different polyurethane foam test block grade materials used are given in Table 2.

Table 2: Mechanical properties of the PU foam specimen material [5]

Density (g/cm ³)	Compressive (MPa)		Tensile (MPa)		Shear (MPa)	
	Strength	Modulus	Strength	Modulus	Strength	Modulus
Low Density 0.24	4.9	123	3.7	173	2.8	33
High Density 0.64	31	759	19	1000	11	130

The work is based on the comparison of two different implantation techniques used to insert cementless acetabular cup implants. The implants were inserted into the PU foam blocks using the manual and powered impaction techniques. This study was focused to explore the significance of a powered automated technique which could have the potential to replace the current mallet and shell introducer instrument technique. Therefore, the automated technique will have improved surgery success and quality patient life.

Experimental

Implants used for the experimental tests were *Trident*[®] *PSL*[®] Acetabular cups with *PureFix*[™] Hydroxyapatite (HA) coating, manufactured by *Stryker*[®] *Howmedica Osteonics*. The dimensions of the rigid PU foam test blocks for each of the two different densities, were 180 mm x 130 mm x 40 mm. Both low density and high density grades of rigid PU foam were used. The low density and high density PU foam blocks represent the two different properties of cancellous bone, tensile and compressive strength. There were three different variables for each of the experimental tests which were carried out. These variables were, implant size, test block specimen material, and impaction technique used. The 50 mm and 52 mm cup implants were used for both the pull-out and lever-out experimental tests. The 54 mm cup implant was used for the torque tests. For pull-out tests, both 50 mm and 52 mm cup implants were inserted into and tested in the low density PU foam. The 50 mm cup implant was inserted into and tested in the high density PU foam test blocks.

This was also the case for the lever-out tests. For torque tests, the low density PU foam blocks were used with size 54 mm cup implants. For each combination of implant size and test specimen, each test was repeated five times for both the manual and powered insertion techniques. The metal bench vices were used to hold the test blocks securely in place during the reaming and cup implantation procedures. The remaining preparation of the hemispherical cavity was carried out by using the cordless drill and adapter together with the acetabular reamer instrument and reamers. The purpose of reaming the PU foam blocks was in order to create a roughened surface inside the hemispherical cavity which in turn would improve the stability of the inserted implant. The reaming was carried out to mimic the real life surgical technique and the reaming guideline followed is outlined in Table 3.

Table 3: PU foam block reaming guideline

Block type	Implant label size, mm	Implant actual size, mm	Amount of Oversizing, mm
Low density	50	51.8	1.8
	52	53.8	1.8
	54	55.8	1.8
High density	50	51.8	0.8
	52	53.8	0.8
	54	55.8	0.8

(i) Manual Cup Implant Impaction

After hemispherical cavity was reamed out from the PU foam test blocks to the appropriate size, the test blocks were securely tightened and in the correct position within the bench vice. The cup implant was then threaded onto the end of the shell introducer instrument and inserted into the hemispherical cavity. The impaction instrument was positioned upright with its central axis perpendicular to the top surface of the test block. This position was maintained until the cup was fully inserted. The impaction instrument was then hit with several blows of the mallet until the rim of the implant was in line with the rim of the hemispherical cavity.

Once this rim-to-rim alignment was achieved, the implant was considered to be securely fit and was ready to be tested. The shell introducer instrument was then unscrewed from the cup implant. Both the shell introducer instrument and mallet, were products of Stryker® Howmedica Osteonics. The slotted mallet was medical grade and made from stainless steel. These two instruments together formed the manual impaction technique apparatus.

(ii) Powered Cup Implant Impaction

Similar to the manual impaction cup insertion technique, the modified impaction instrument with attached cup implant was inserted into the hemispherical cavity of PU test block. The powered impaction device was then placed down over its connection at the opposite end of the modified impaction instrument. The trigger of powered impaction device was then pressed to initiate the hammer action and held until the rim-to-rim alignment was achieved between the implant and the hemispherical cavity, indicating a secure fit. The percussion hammer tool was then lifted away from the modified impaction instrument and the instrument was unscrewed from the cup implant. The percussion hammer tool used for the powered cup impaction technique was an Einhell® DMH 250/1 pneumatic chisel hammer. The device was designed to operate at a maximum permissible working pressure of 6.2 bar and was powered using the compressed air supply which could be manually adjusted to supply between 0 and 10 bar of compressed air. The device had a stroke length of 63 mm with a blow rate of 3000 blows/min or 50 blows/sec.

The design the pull-out and lever-out test setups originated from the test setups used by Arts et al. who carried out similar experimental tests on cementless acetabular cup implants [6]. The machine used to carry out the pull-out and lever-out experimental tests was a Zwick/Roell™ all-round universal static testing machine capable of dealing with forces of up to 50 kN. The testing machine was linked up to computer which enabled to obtain test results and experimental statistics to a high degree of accuracy.

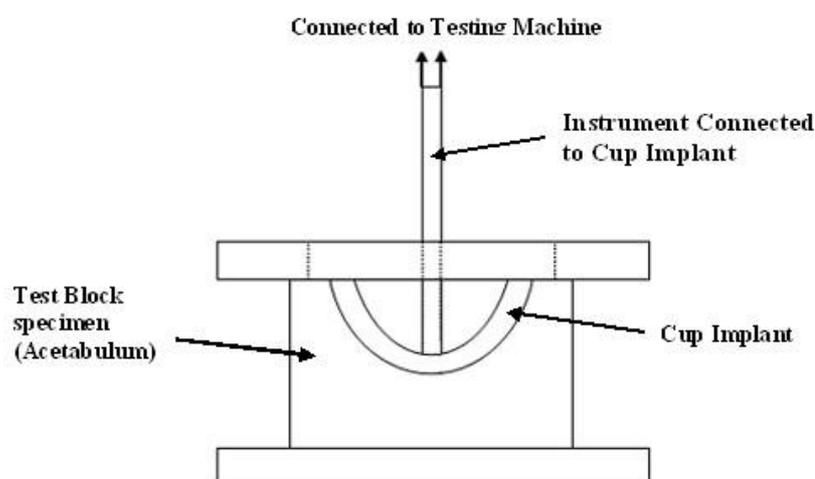


Fig. 1: Schematic diagram of pull-out force test setup

The schematic diagram in Fig. 1 describes the pull-out experimental setup. The test block specimen was firmly secured in the test block holder with a 0° angle of inclination from which the fixation instrument extended from the inserted cup implant at an angle of 90° . The machine vice applied a tensile force on the cup implant in the vertical direction at a speed of 10 mm/min, gradually pulling the cup implant out of the test block specimen. Toward the end of each test, the cup implant could be seen and heard to release out from the PU block specimen therefore confirming that the pull-out of the cup implant had been achieved.

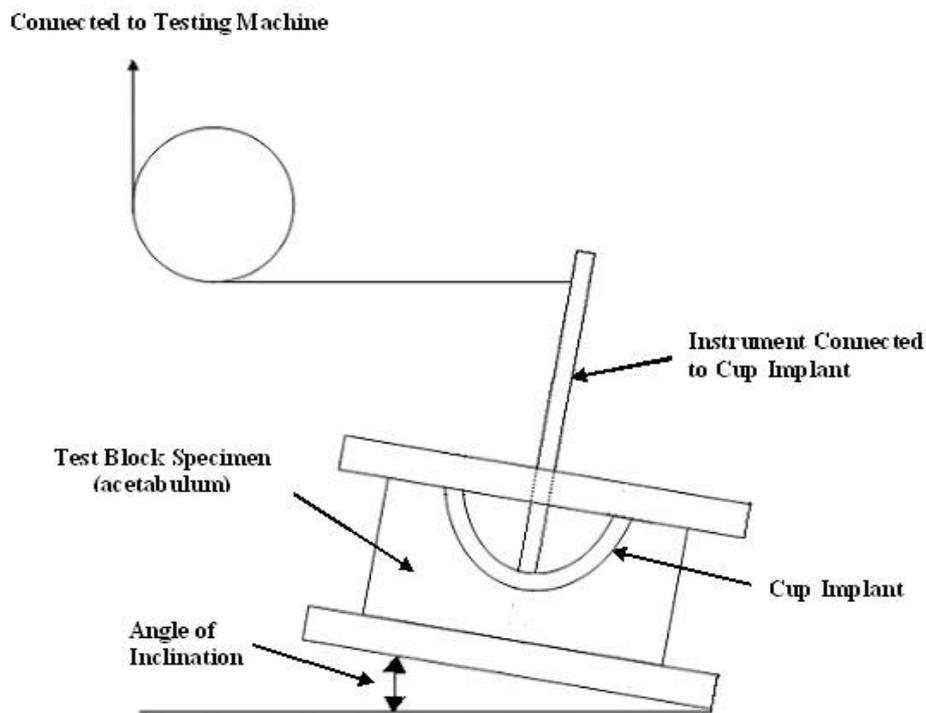


Fig. 2: Schematic diagram of lever-out force test setup

The 10° angle of inclination was built into the setup to ensure that only lever-out forces were being used to separate the cup implant from the test block specimen, with no pull-out action. A schematic of lever-out test setup is shown in Fig 2. For this test, PU block was secured in the test block holder at a 10° angle of inclination. The force from the test machine was transferred from the vertical direction to the horizontal direction using the pulley and cable system. At the machine vice, the cable was inserted through the pin hole and crimped along the length of the cable to form a secure closed loop system. At the fixation instrument, a pre-formed closed loop cable and crimper system was placed down over the top of the fixation instrument as far as the ridge between the bottom and top parts of the fixation instrument. A speed of 10 mm/min was applied until the cup implant was levered out of the cavity of PU test block specimen.

A manual torque wrench was used to carry out the torque testing. The setup included the use of the torque wrench and spanner which were connected up to the shell introducer instrument. The torque wrench had a range of 10-80 Nm or alternatively 88.5-708 lb/in. The range of torque could be increased in 1 N/m increments. The test block specimens with the inserted

cup implants were secured in the workshop bench vice. Two parallel flat surfaces along the cylindrical metal shaft of the shell introducer instrument allowed to secure connection made with a standard size 11 spanner. The handle of shell introducer instrument was then held securely whilst the torque wrench and attached spanner were rotated at 90° to the shell introducer in one plane of motion. The handle of the shell introducer was allowed to rotate with the rotation of the torque instrument and spanner.

Results and Discussion

The results from the pull-out, lever-out and torque tests can be seen in Fig. 3. It can be seen from Fig. 3a that it required more force to remove both the 50 and 52 mm cup implants from the low density PU foam blocks for powered technique. However, in terms of the high density PU foam test block, there was only a difference of 15 N between the mean values for the two data sets. This difference in force was relatively small and insignificant when comparing the overall magnitude of the forces required to remove the cup implants from the test block specimen. Using these force values extracted from each test series at each 0.5 mm increment, the mean force value was calculated, and the highest and lowest force values were recorded.

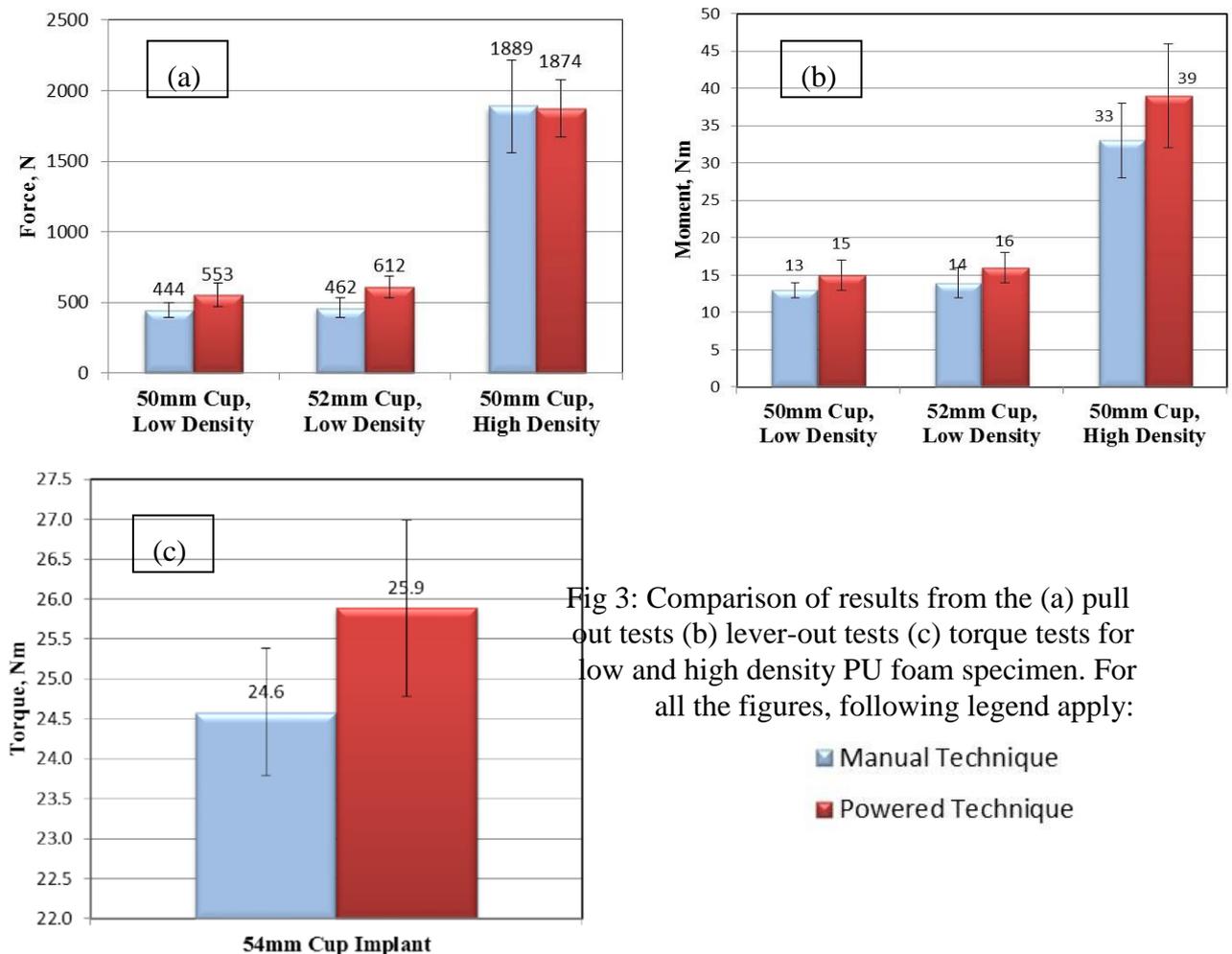


Fig 3: Comparison of results from the (a) pull out tests (b) lever-out tests (c) torque tests for low and high density PU foam specimen. For all the figures, following legend apply:

- Manual Technique
- Powered Technique

A bar chart representing lever-out tests results can be seen in Fig. 3b. From this bar chart, it can be seen that it required a greater moment of force applied to the cup implants inserted using the powered impaction technique, for both the high and low density PU foam. From this Fig. 6b, it can be seen that there was a large deviation in the error bars at the peak force stage in the plots for the data series at displacements of 10 mm and 12.5 mm respectively for the 50 mm cup implants inserted into the high density specimen material. This error deviation was evident for the plots describing the implants inserted using both the manual and powered impaction techniques.

The torque results were based on using the 54 mm cup implants inserted into the low density specimen material using both the manual and powered impaction techniques. Fig. 3c shows a graphical representation of the torque test results given. It can be seen from this bar chart that, the cup implants which were implanted using the powered impaction technique required a higher torque to initiate rotational movement within the cavity. The overall accuracy of the results was reduced due to the limitations of the torque gauge. As torque gauge could only be adjusted in increments of 1 Nm, when rotational motion of the cup was initiated, the value for the torque was recorded as being that of the set torque wrench value.

For the press-fit technique of implanting acetabular cups, the acetabulum is generally oversized between 1-3 mm with any further over-sizing increasing the risk of possible pelvic fracture. As a result of this over-sizing, a substantial amount of impaction force is required to seat the implant correctly into the bed of the acetabulum [7]. The technique of manual impaction for surgical acetabular cup implantation was investigated by Kroeber et al. and reported that the acetabular cup implants were effectively seated after between 3 and 5 impacts of the mallet against the impaction instrument in 4 out of 5 tests carried out and that the effective mass remained relatively constant throughout the experiment [8]. Kroeber et al. concluded that the bone strains increased during the cup insertion similar to how they would do with elastic and plastic deformation of the pelvis. Acetabular cup implants can experience a certain amount of mechanical deformation during surgical insertion using the manual impaction technique[9].

Summary

- The use of the percussion hammer tool to insert the cup implants improved the implants stability and fixation. This was evident due to the increased forces, moment of forces and torque required to remove the cup implant inserted using the powered technique compared to the manual impaction technique.
- The accuracy of cup implant alignment and seating was improved using the powered impaction technique. This was due to the high speed of cup impaction using the percussion hammer tool.
- Compared to the manual impaction technique, the use of the percussion hammer tool reduced the magnitude of the shock forces which were applied to the cavities of the specimen material during the cup insertion.
- The use of the percussion hammer tool as a powered impaction instrument to insert cementless acetabular cup implants was a significant improvement of the current manual insertion technique.

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