

Testing the stability of the polyethylene acetabulum cemented on a frozen bone graft substrate on a model of an artificial hip joint

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The stability of the polyethylene acetabulum cemented on a substrate made of frozen bone grafts was investigated. The force was applied to the edge of the acetabulum and the magnitude of the force and resulting displacement were recorded. These tests were preceded by stress testing, during which the acetabulum was subjected to loading forces of 1 or 3 kN through 100,000 cycles. Additionally the influence of the thickness of grafts layer on the overall stability of an implant was also determined. The experiments proved that such factors as initial compacting of bone grafts, magnitude of the loading force and thickness of grafts layer greatly affect the stability of the artificial acetabulum.

Key words: impacted bone grafts, hip joint acetabulum, stability of acetabulum

1. Introduction

The expansion of joint replacements in the 1970s has resulted in a large group of patients who require revision arthroplasty for aseptic loosening. Structural damage to the periarthritic bone stock is a major challenge in joint prosthesis revision surgery. To fill the bone defect and stabilize the new cup, impaction of morsellized bone is a common procedure [2]–[7].

Initial stable fixing of the acetabulum in revision hip arthroplasty is the key element that leads to proper remodelling of bone tissues [8]–[10]. Proper fixing of the acetabulum also makes it possible to the apply a load to the prosthesis, which speeds up the process of regaining full fitness of a limb. Little is known about the factors affecting the stability of acetabular cups obtained after bone impaction grafting combined with cemented cup placement. Previous research was estimated and the optimal value of compacting force and mechanical parameters of compacted bone grafts were determined

[11]–[15]. Our next step was to experimentally investigate the stability of the acetabulum cemented on a substrate made of frozen bone grafts. Traditionally, bone grafts are impacted with impactors and a mallet. However, some surgeons use a modified impaction technique in which the bone grafts are impacted using an acetabular reamer in a reversed direction in combination with manual compression on the reamer [16].

2. The aim of the study

Our research will make it possible to estimate the stability of the acetabulum after the surgery. The relocation of the acetabulum greater than 5 mm is usually considered as stability loss. Knowing the threshold values of loading force that affects stability it will be possible to adjust rehabilitation loads properly.

The research was focused on testing the stability of the artificial hip joint acetabulum cemented on a sub-

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strate made of frozen bone grafts. The influence of the thickness of the substrate layer on the overall stability was investigated as well as the resistance of cemented acetabulum to cyclically variable loads of different magnitudes.

3. Material and methods

The tests were carried out on synthetic models of a hip joint, whose construction is depicted in figure 1. These models were prepared by the orthopedist in a special cylindrical vessel of 68 mm in diameter and made of epoxy resin. For the experiments, bone grafts were used, obtained from femoral heads. After the removal of cartilaginous tissue and defatting, the bone grafts were ground down to create bone chips of about 5–8 mm in diameter. Then the grafts were frozen. Sterilization by ionizing radiation was not applied. The same investigator did all the reconstructions. Bone graft samples were prepared in a spherical vessel created inside a cylinder of 68 mm in diameter (figure 1). Each sample has 3 layers of bone grafts compacted successively with compactors of decreasing diameter (down to 50 mm) until the desired shape was obtained ready for the artificial acetabulum to be cemented in. After initial compacting, the bone grafts were subjected to sinusoidally changing load of 1 Hz frequency. For every layer of grafts a series of 30 compacting cycles was performed and the force changes versus displacement were recorded.

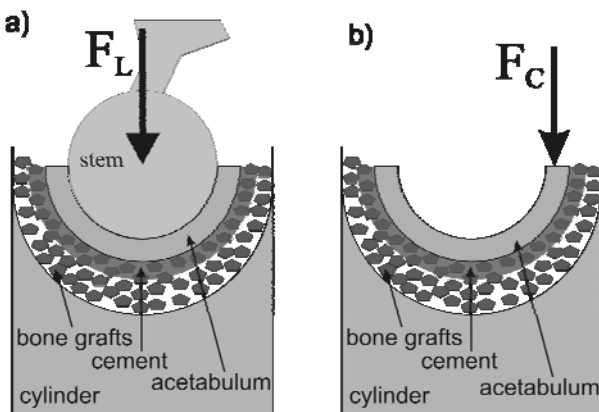


Fig. 1. Models used during: a) load tests, b) shearing tests

The polyethylene acetabulum was cemented on a layer of compacted bone grafts 1 or 2 cm thick. Next, the acetabulum was subjected to cyclic loading force F_L through 100,000 cycles in a set-up presented in figure 1a. During cyclic tests a sinusoidally changing force of 1 Hz frequency and amplitudes of 0.5 kN and

3 kN was used. When these tests had been completed, the stability of the acetabulum was tested by applying a shearing force F_C to it (figure 1b). The compacting process was carried out with INSTRON 8501 Plus stress-testing machine. Static and dynamic loads of various shapes can be applied on a test stand by controlling the process using force or displacement measurements. Measuring accuracy is 0.5% of the measuring range in the case of loading force measurement and 0.01 mm for displacement measurement.

Five consecutive tests were carried out for three different force values ($F = 0, 0.5$ kN and 3 kN), two thicknesses of bone graft layer ($D = 1$ cm and 2 cm) and for two different loading cycles ($n = 0$ and $n = 100,000$).

4. Test results

During cyclic loading tests, a displacement of the acetabulum was observed in the direction of loading force F_L . The magnitude of this displacement depends on the value of the loading force and on the thickness of bone graft layer. The results are presented in table.

Displacement of acetabulum after 100,000 cycles

Test No.	F_L [kN]	Thickness of bone graft layer D [mm]	Displacement after 100,000 cycles [mm]
1	0	10	0
2	0.5	10	0.48
3	3.0	10	0.5
4	0.5	20	0.37
5	3.0	20	2.15

The displacement of the acetabulum is very similar for 1 cm graft layer, regardless of the loading force, and amounts to about 0.5 mm. Such a small displacement is due to stiffening effect of the cement on which the acetabulum was fixed. The cement penetrates the free spaces between the grafts and increases their overall mechanical strength. In the case of a thicker layer, the additional strength introduced by the cement is only sufficient to withstand 0.5 kN of the loading force, whereas greater load of 3 kN results in considerable displacement, 2.15 mm, which is 10% of the total thickness of the grafts layer. This is caused by additional compacting of the graft layer by a force of this magnitude.

After the loading tests, the acetabulum was subjected to shearing force (see figure 1b). During this

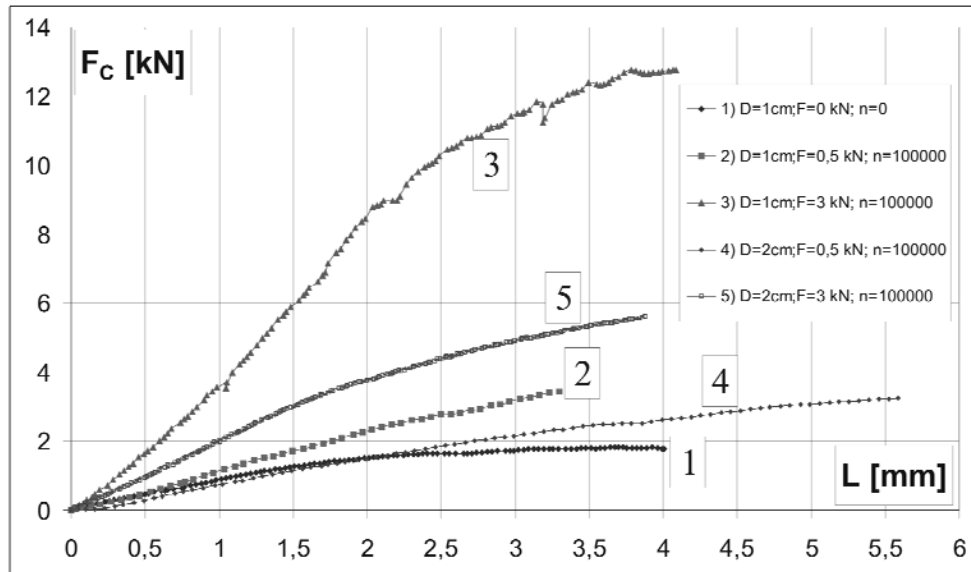


Fig. 2. Shearing force F_C versus the displacement L of acetabulum

experiment the value of the force was gradually increased and its value F_C and the corresponding displacement L of acetabulum were recorded. The results are presented in figure 2.

The value of the force necessary to tear the acetabulum off depends on the thickness and the quality of compacting the bone graft layer. This can be clearly seen in the results of tests no. 1, 2 and 3 where the layer was 10 mm thick. In the test no. 1, the acetabulum was cemented on the grafts compacted by the orthopedist only, with no additional load applied afterwards. In this case, the breaking force is the much smaller than in test no. 3 and smaller than in test no. 2, where the same sample was subjected to cyclic load of 0.5 kN through 100,000 cycles. It should be noticed that although vertical displacements were similar for both loading forces (0.5 and 3 kN), the process of tearing the acetabulum away is quite different and shows the compacting effects of 3 kN cyclic force load.

For thicker layer $D = 20$ mm the differences in the breaking force are not as great as those for thinner layer in spite of very different vertical displacements of the acetabulum under cyclic load (see table).

5. Discussion

Revision surgery of failed hip prosthesis components is accompanied by complex problems. Several methods have been suggested to cope with the bone stock loss. An increasing number of revisions that

have to be performed in the near future result in the growing need for improving the procedure. The cemented cups were more stable when the reconstruction was performed with large bone chips and when a firm impaction with metal impactors and a hammer was applied [9], [11]–[13], [17], [18]. Simplified models provide information about the mechanical characteristics of the impacted morsellized bone grafts [10], [13], [17]–[21]. However, in most simplified models, the interaction with the bone cement of the bone grafts is not considered. The synthetic acetabulum model was introduced to overcome these problems.

Greater force applied during cyclic loading results in the increase in mechanical strength of bone graft layer and therefore increases overall durability of the biomechanical system analyzed [12], [13]. This reduces the probability that acetabulum gets loose in the early post-operation stage which can be seen by comparing the results of tearing off tests for samples no. 2 and 3 and for samples no. 4 and 5. Such a statement leads to the conclusion that proper loading applied to the limb during rehabilitation is highly recommended. But simultaneously a question arises where the borderline between the benefits and dangers of such an approach is.

During the tearing-off tests it was discovered that increasing the thickness of the graft layer increases also the potential acetabulum stability problems, as was found for samples no. 2 and 4 and for samples 3 and 5. Therefore, the rehabilitation program should be matched to an individual patient, taking into account the thickness of bone graft layer used to reconstruct a hip joint. The experiments

pointed out that the key factors affecting the stability of the acetabulum cemented on a layer of one graft are:

- initial compacting of bone grafts,
- proper loading of the cemented acetabulum, which increases the mechanical strength,
- thickness of the graft layer,
- magnitude of the breaking force.

Much smaller forces cause the instability of the acetabulum on a thick layer of bone grafts than on a thin one. There are several reasons for that. Thin layer (in that case 1 cm) compacted and then loaded exhibits greater mechanical strength than a thick one. Furthermore, the cement penetrates both layers to the same depth, thus increasing the mechanical strength of a thin layer. In the case of thick layer, many pieces of grafts have no contact with cement at all. From the clinical point of view, an increase in the thickness of a graft layer may increase the risk of the acetabulum to get loose.

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