Effects of screw eccentricity on the initial stability of the acetabular cup

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Abstract One of the major failure modes of cementless acetabular components is the loosening of the acetabular cup, which is mostly attributable to insufficient initial stability. A hemispherical cup with a porous coating which is inserted with press-fit fixation and secured with several screws is one of the most widely used approaches. Many studies have found that bone screws are very helpful aids for cup fixation, but the optimal surgical technique for inserting screws has not been clearly reported. In this study, hemispherical cups were fixed into blocks of foam bone with zero to three screws. The effects of three types of screw eccentricity (a 1-mm offset and angular eccentricities of 15° and 25°) on the initial stability of the acetabular cup were evaluated. The experimental results indicate that increasing the number of screws enhances the cup stability in the case of ideal screwing (i.e., with no eccentricity). An angular eccentricity of 15° did not affect the cup stability

for fixation with one or two screws. However, the presence of 25° of angular eccentricity significantly reduced the stability of the cup, while 1 mm of offset eccentricity produced an even greater impact.

Résumé Les modes les plus fréquents d'échecs des prothèses sans ciment sont le descellement de la cupule acétabulaire. Ce descellement est souvent en relation avec une stabilité initiale insuffisante. La cupule hémisphérique avec revêtement mis en place en press-fit avec vis additionnelles est un des modes opératoires les plus utilisés. De nombreuses études ont montré que l'utilisation de vis permettait de sécuriser la fixation. Pour cette étude, nous avons fixé des cupules hémisphériques dans un bloc d'os artificiel avec 0 à trois vis. Les effets de trois types de vissage ont permis d'évaluer la stabilité initiale de la cupule. Cette étude expérimentale montre que plus les vis sont nombreuses, meilleure est la stabilité. Une fixation excentrique de la cupule à 15°, stabilisée par une à deux vis n'a pas de conséquences néfastes, cependant une excentricité de 25° diminue de façon significative la stabilité de la cupule, de même, en ce qui concerne l'offset avec excentration de 1 mm.

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Introduction

Total hip replacement (THR) is a common surgical procedure in orthopaedics. One of the most common failure modes of the cementless acetabular cup is its loosening, which is mostly due to insufficient initial stability after implanting the cup into the pelvis [5, 14, 15, 20]. The hemispherical cementless acetabular cup fixed with multiple screws is one of the most popular approaches in THR [3, 7, 16, 17], with many studies finding that bone screws are very helpful aids for cup fixation [4, 8, 9, 11]. However,

most of the studies have focused on the effect of the number of screws or their locations on the initial stability of the acetabular cup [4, 8, 11, 18], with (to our knowledge) no reports on the effects of the suboptimal surgical technique used to insert screws on the initial stability of the acetabular cup. In this procedure, the surgeon has to predrill holes in the bone before inserting the screws, where the screw drill is controlled by a drill guide as it passes through the screw hole on the cup. If the screws were inserted at the correct position and in the correct direction, the use of screw fixation should, theoretically, enhance the initial stability of the acetabular cup. However, screw eccentricity sometimes occurs due to the restrictions of surgical exposure and the limited view of the surgeon. Such eccentric screw insertion creates tangential forces that could result in the movement of a well-fitted cup [10, 13, 21], thereby, reducing the initial stability of the acetabular cup [19].

This study tested the influence of screw eccentricity on the initial stability of the acetabular cup.

Materials and methods

A commercial hemispherical acetabular cup (58-mm outer diameter) with 12 screw holes (Pinnacle, Depuy, Warsaw, IN, USA.) was used in this study. Three screw holes were selected (labeled A, B, and C) as the target screw holes (Fig. 1), and screw eccentricity was classified into offset eccentricity (Fig. 2a) and angular eccentricity (Fig. 2b). This study evaluated the effects of two angular eccentricities (15° and 25°) and one offset eccentricity (1 mm)

Fig. 1 Positions of the three screws on the acetabular cup

Fig. 2a, b Types of screw eccentricity during fixation: (a) offset and (b) angular

(Table 1). All of the screws (6.5-mm inner diameter and 25-mm long) were tightened to a torque of 4 Nm.

In principal, the use of frozen fresh human cadaveric pelvises would have been preferred, but obtaining the necessary number of specimens with identical bone quality and acetabulum size would have been difficult, if not impossible. Therefore, in this study, we used foam bone (Sawbones, Vashon, WA, USA) whose elastic modulus (380 MPa) and density (0.38 g/cm³) were similar to those

Table 1 Displacement data of the acetabular cup with different screw configurations

Number of screws	Screw configuration	Displacement (microns, mean±SD)
0	None	86.3±2.1
1	A	42.6±2.7
	A (1 mm)	58.3±1.7
	A (15°)	43.8±4.7
	A (25°)	50.9±2.0
2	A–B	35.1±3.7
	A (1 mm)–B	52.1±0.7
	A (15°)–B	35.6±0.8
	A (25°)–B	47.5±0.8
3	A–B–C	24.4±5.8
	A (1 mm)–B–C (1 mm)	69.6±1.5
	A (15°)–B–C (15°)	45.6±1.9
	A (25°)–B–C (25°)	46.1±3.8

The parenthesised values in column 2 correspond to the eccentricity offsets and angles.

Fig. 3 Schematic cross-section of the experimental setup

of pelvic cancellous bone. Blocks of foam bone with dimensions of 140×100×76 mm were prepared, and a surgical reamer attached to a drill press was used to ream the foam bone to a diameter of 57 mm, so as to obtain a 1-mm press-fit.

A compressive force of 1,500 N was applied to ensure seating of the acetabular cup in the foam bone prior to testing. Fluoroscopy was used to confirm that the cups were in intimate contact with the surface of the cavity. Linear loads of 0 N to 1,000 N were applied using a testing machine (MTS, Minneapolis, MN, USA) at a speed of 0.05 mm/s to the flat rim of the acetabular cup located at the opposite side of the screw region so as to impart a shear load to the interface between the cup and the foam bone (Fig. 3). The motion of the cups were monitored with a laser-based displacement sensor (ANR1251, NAIS, Kadoma, Osaka, Japan) from the opposite side of the rim.

Each configuration was measured three times. The data were analysed using one-way ANOVA plus Duncan's multiple-range test to ascertain the pairwise effect of screw eccentricity on the initial stability of the acetabular cup.

Results

No GROSS failure of the fixation occurred during the loading of any of the cups up to 1,000N. The experimental results given in Table 1 and Fig. 4 indicate that the most unstable case was when the cup was fixed without additional screws. For the ideal configurations (i.e., in the absence of eccentricity), increasing the number of screws enhanced the cup stability ($p<0.01$); with single-screw fixation as the baseline, adding the second and third screws decreased the cup displacement by 17.6% and 42.7%, respectively.

The presence of 1-mm offset eccentricity significantly reduced the cup stability relative to the ideal configurations, irrespective of the number of screws ($p<0.01$). However, for angular eccentricity, there was no significant difference between A and A (15°) or between A–B and A (15°)–B. However, significant reductions in cup stability occurred for A (15°)–B–C (15°) and for all configurations with a 25° angular eccentricity ($p<0.01$).

Discussion

This study used blocks of foam bone to ensure uniform material properties between samples [1, 11, 12]. Although the offset loading here is not a common physiological

Fig. 4 Displacement of the acetabular cup for different screw configurations. The error bars indicate the standard deviation (SD) values

loading, it is thought to provide a more stringent test of initial fixation than axial or torsion loading [9]. Moreover, there are many reports that offset loading is suitable for evaluating the initial stability of the acetabular cup [11, 12].

The experimental results obtained here indicate that, in the presence of ideal screwing, increasing the number of screws increases the cup stability, which contrasts with Kwong et al. [8] and Won et al. [22], who reported no significant difference between one and three screws. There are many factors that could contribute to the differences between our study and the previous experiments, such as the different loading type and the variations in the quality of their cadaver pelvic bones. Moreover, screw eccentricity may have occurred in their in-vitro experiments, which is supported by the results in Table 1 and Fig. 3, which indicate that inserting extra eccentric screws does not enhance the cup stability. For example, the displacement in the case of a single ideal screw is less than when eccentricity is present with either two or three screws.

Inserting a single screw with a 1-mm offset eccentricity increased the cup displacement by 36.9% compared with the ideal configuration (Table 1). Moreover, when using two and three screws, the presence of a single eccentric screw and two eccentric screws increases the displacement by 48.4% and 185.2%, respectively. These results indicate that the impact of screw eccentricity increases with the number of screws used for fixation. This may be due to the cup being slightly rotated to a new well-fitted position in the case of single-screw fixation, whereas for multiple screws, the cup cannot adjust its position due to it being locked by the additional screw(s).

In general, the head of a commercial bone screw is shaped as a “fisheye” so as to tolerate a small degree of angular eccentricity. The tolerance of the screws used in this study was 15°, and is consistent with our finding that the presence of a 15° angular eccentricity did not produce adverse effects for both one- and two-screw fixations and that an eccentricity angle of 25° had significant effects on the cup stability.

This study demonstrates that both the skill of screw insertion and the number of screws have significant effects on cup stability. After removing the screws, we observed some metal fragments in the screw-head–hole interfaces in the groups with offset or angular eccentricity. There are many reports that fragmentation or debris can induce acetabular osteolysis [2, 6, 13], indicating that screw eccentricity not only reduces the cup stability, but also promotes osteolysis.

This study is subject to some limitations. The sample was small and the loading type cannot reflect all physiological loadings. Moreover, we investigated only three configurations of screw eccentricity: one offset and two angular. However, these limitations would not affect the

main conclusion of this study, which is that the presence of screw eccentricity affects the initial stability of the acetabular cup. Surgeons should keep this in mind when performing screw insertions in THRs.

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