OPTIMAL POSITIONING FOR ACETABULAR CUP AND CANCELLOUS FIXATION SCREWS IN TOTAL HIP REPLACEMENT SURGERY

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ABSTRACT

Acetabular cup positioning in total hip arthroplasty has become the most problematic part in this type of orthopedic surgery, given that there are a series of factors which are difficult to control, such as age, gender, medical conditions, reduced space and approach chosen. In this article, twelve cadaveric pelvises were analyzed by image processing and CAD software, to find the optimal combinations between the fundamental angles involved in cup orientation. The results of this work show that cup rotation between the first and third quadrants of safe zones could withhold longer screws without putting at risk important structures surrounding the pelvis. Optimal anteversion and abduction angles also help to avoid danger areas and a more serious complication such as dislocation in a hip replacement. The analyses show that 30 - 40 mm screws fit without risk with 15° ± 5° anteversion and 45° ± 5° abduction angles, if they are in the first and third quadrants of the pelvis. Any screw outside this area could seriously risk one or more structures near the pelvis, with dangerous consequences to the patient.

Keywords: Acetabular cup, total hip replacement, screw positioning, safe zones

Introduction

Acetabular cup positioning has a significant effect on the outcome of total hip arthroplasty (THA) and often leads to dislocation altogether with factors like age, sex, medical conditions and the surgical approach selected [1]. The surgeon though, has control over the surgical approach, the implant selected and mainly the implant positioning. However, implant positioning is often a difficult variable to control during minimal invasive surgery given that the intraoperative surgical space is reduced and visibility is limited. To describe a method that quantified and averaged data gathered in human specimens Krebs et al. [2] developed a standard representation of the pelvis, where topographic features such as the ilium and ischium allowed a reconstruction of the hip. They divided the pelvis in four zones and used these areas to define the safe zones of the acetabulum, such as the superior iliac column and the area between the angle of the top sciatic notch and the line that bisects the ischium.

Wasielewski et al. [3] found four quadrant zones reliable for screw placement, drawing a line dividing the pelvis by the ASIS (Anterior Superior Iliac Spine) to the posterior fovea and a second line perpendicular at the midpoint of the acetabulum. The study found that the anterior quadrants, superior or inferior, should be avoided given that structures like the external iliac and obturator nerves, arteries and veins are highly at risk, in contrast with posterior superior and inferior quadrants, which contain in most cases enough available bone stock for proper attachment of the screws.

Sotereanos et al. [4] provided three bony landmarks, identified intraoperatively as ilium, superior pubic ramus and superior acetabulum, to define a plane, and based on it determine a suitable cup anteversion or retroversion. The plane can provide a relationship between the acetabulum and the structures at risk behind it. However, there is no established relationship between this plane and the safe zones at moment. The planes used to define abduction and anteversion, in relation with conventional CT scans, were defined in the study by Stem et al. [5], where 100 CT scans were analyzed to accurately outline a normal range of acetabular abduction angles as 31° - 46° and anteversion angle of 23° [6].

A wide range of abduction (40° ± 10°) and anteversion angles (15° ± 10°) are used to lower the probability of hip dislocation and to make sure a good bone stock area is available [7]. Liu & Gross [8] also confirmed that in abduction angles over 50° failures were not observed.

Even though the safe zones and proper angles of anteversion and retroversion are a good guide during a surgical procedure, awareness of where the screws will fit without interfering with cortical zones is crucial to avoid injuries in vital intrapelvic structures and key for an optimal acetabular cup positioning [9].

The current study is intended to validate the safe zones exposed by Wasielewski et al. [3], based on three-dimensional CAD models, as well as to determine the position of the cup that accepts the longest length of screws conforming with good bone stock. Also, it is intended to study the angle in which the screw has the optimal amount of bone stock available to improve fixation and lower the risk of injury.

2 Materials and methods

A total of 12 cadaveric pelvises were scanned by Computer Tomography (CT). These specimens were divided in 6 Japanese and 6 Caucasian cases (3 men/ 3 women for both). A Design of Experiments Analysis (DOE) using a full factorial design with 4 factors was applied. The factors were the acetabular anteversion angle, the abduction angle, the screw hole utilized for a specific model of an acetabular cup and the patients' gender.

The cup size was determined by Argenson et al. [10], who used the CT view passing through the center of the acetabulum, which determines preoperatively the size that would match the anatomy of the patient. The acetabular anteversion angle was considered the angle measured from a transverse view starting from the sagittal plane up to the line that bisects the femoral head and femoral neck. This angle is recommended to be 15° ± 10°. The acetabular abduction angle was considered a measurement calculated from the horizontal line formed by the triradiate cartilages and the line parallel to the surface of the acetabular cup. This angle is recommended to be 40° ± 10° [4].

The image segmentation operation was performed with MIMICSTM software version 16. Furthermore, the images were converted into IGES (Initial Graphics Exchange Specification) models in 3-Matic 8.0 preparing them to then import into SolidWorksTM 2013 to perform the DOE experiment. To be modeled in MIMICS, the CT images were required to have at least 10 mm proximal from the ASIS, the acetabulum, the acetabular fossa and the pelvis symphysis which is the soft tissue between the pubic tubercles. This process is shown schematically in Figure 1.

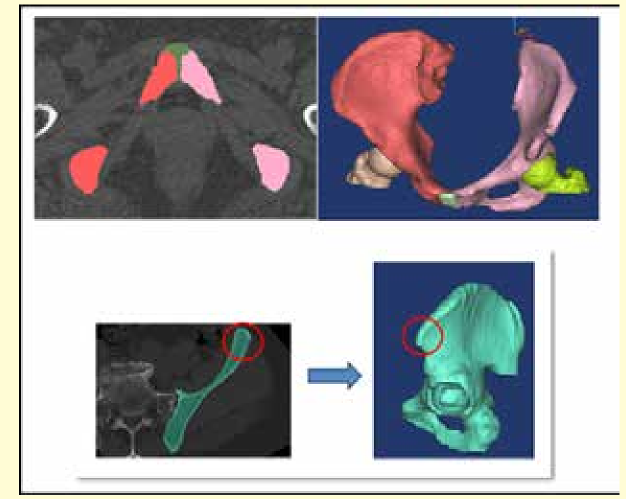

Figure 1 Image segmentation of the study

The response variables associated with the study were the optimal angle with enough available bone stock, the maximum screw length, and the distance to the cortical bone for the corresponding maximum screw length. The maximum screw length response variable corresponds to the maximum size that fits before intersecting with the cortical bone. The optimal screw angle was measured as the angle that holds more bone stock and was not likely to intersect or trespass the cortical bone. The cup orientation was defined by the anteversion and abduction angles. A parallel plane to the surface of the cup was created to set the rotation that will then determine the safe zones. Every cup rotation was analyzed within all the possible combination of angles and genres. The DOE response variables are shown schematically in Figure 2.

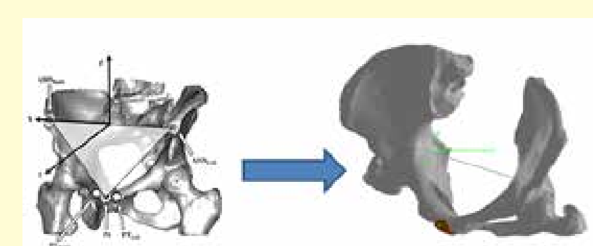

Figure 2 DOE experiment variables graphical description

3 Results and discussion

3.1 Maximum screw length allowed

Some of the data was analyzed manually so that critical points could be determined before analyzing Minitab results. From the obtained data, the maximum screw length was defined depending on the anteversion, abduction and rotation angles. Figure 6 shows the averaged maximum screw length according to the rotation defined. As the rotation increases above 45° the allowable screw length is shorter, which can be explained given that the morphology of the hip bone on that rotation angle is narrower than for the rest of the rotation angles. On the other hand, above 113° the screw length remains constant.

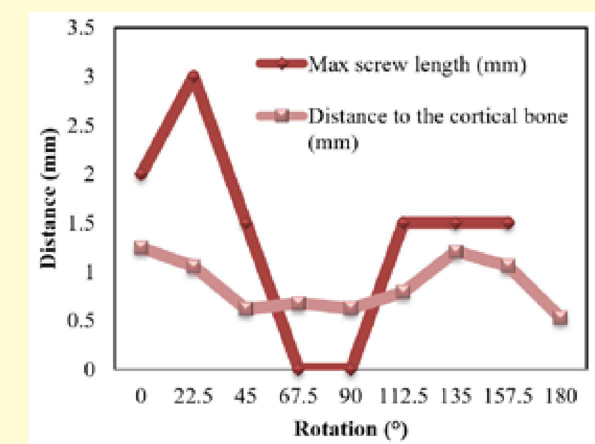

Figure 3. Averaged maximum screw length per rotation

As shown in Figure 4, for a 22.5° rotation, a longer screw is allowed with an abduction angle of 50° when compared with 30°. It is possible that a longer screw can be used if the cup is oriented with an anteversion of 25°. The screw length behavior for a 67.5° rotation is very similar to 90°, where a high value anteversion does not allow screws longer than 2 cm, while 50° abduction does. On the other hand, the longer screw allowed in a pelvis is 30 mm long, any longer screw could represent a high risk for the surrounding nerves and structures of the pelvis.

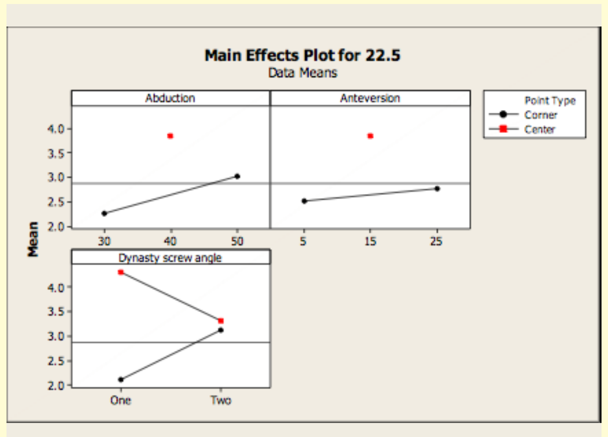

Figure 4 Main effects plot for a 22.5° rotation

As far as interactions between factors is concenrned, for maximum length at 22.5°, Figure 5 shows the high anteversion and abduction angles represent a better screw length result. The gender factor does not generate any interaction however; Dynasty screw angle one altogether with abduction of 40° and anteversion of 15°, maximizes the allowable screw length.

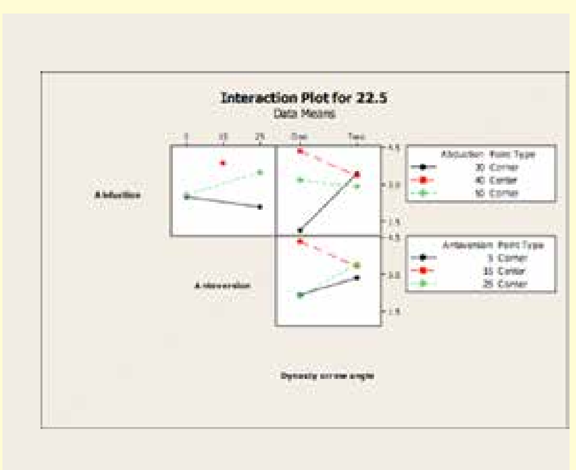

Figure 5 Interaction plot for 22.5°

3.2 Minimum distance to the cortical bone

The overall results of the distance to the cortical bone are shown in Figure 6. The small angulations represent better options of space available between the screw and the pelvis. This also happens with the 112.5° and 157.5° cup rotations; in these sets of rotations the risk of interfering with surrounding structures is considerably lowered. With more space available between the screw and the cortical bone, there is a lower chance of the screw running through the pelvis and causing a more serious injury in the surrounding structures.

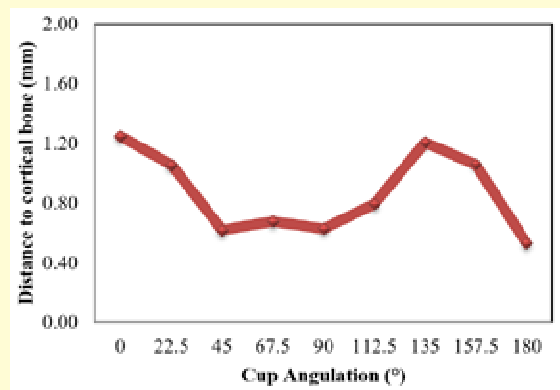

Figure 6 Average distance to the cortical bone per rotation angle

It is also possible to relate these results with those obtained in the maximum screw length allowed in the pelvis, given that with a 22.5° rotation, a 30 mm screw fits with considerable space surrounding it, which would mean a safe path in surgery. These results can be seen in Figure 7. If the results are seen by rotation angle, it can be noted that in an abduction angle of 50° the distance to the cortical bone is averagely higher than in the 30° angle. The previously discussed result justifies the facts that the majority of surgeons utilize a 40° abduction angle for the acetabular cup, since it gives good outcomes.

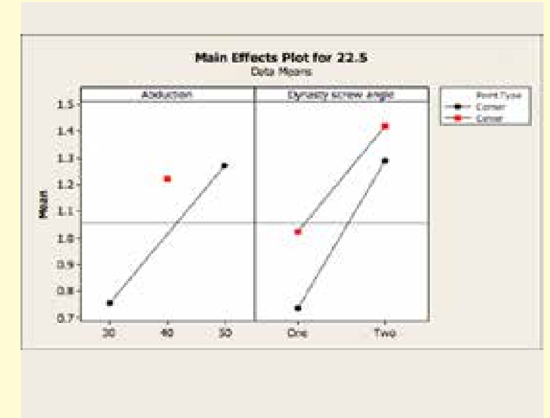

Figure 7. Main effect plot for 22.5°

A survey of the equipment of computerized tomogIn the interactions between independent variables, the distance to the cortical bone is lowered with a maximum abduction and anteversion, as shown by Figure 8. In most of the rotation angles the interactions are significant ($p<0.005$), in a tertiary level. However, the ones that show a considerable change are those that utilize optimal abduction and anteversion angles together with Dynasty screw angle two, in both female and male genders. Based on the study it can be determined that the results obtained when obtuse angles are used, guarantee longer screw lengths and safe distances to the cortical bone.

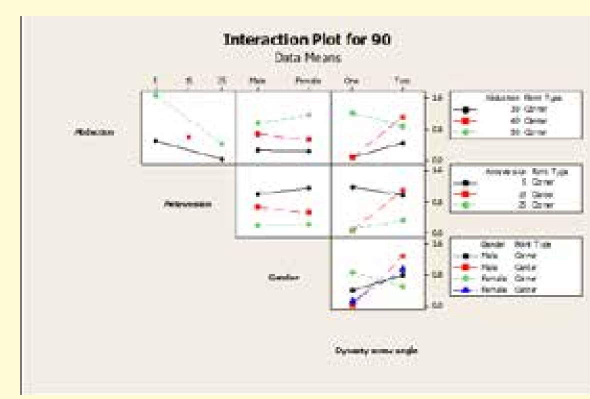

Figure 8 Interaction plot for 90°

3.3 Evaluation of optimal screw angle

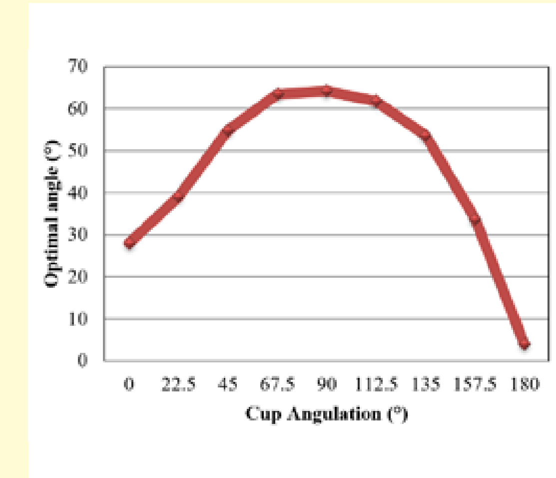

Figure 9 Averaged optimal screw angle for each rotation angle

Figure 9 shows that the screws adapt themselves to the anatomy in the pelvis as the rotation angle increases. In general terms, without taking into account the angles from the limit values (0° and 180°) the optimal screw angle values are similar in the following combinations: 22.5° with 157.5°, 45° with 135° and 67.5° along with 90° and 112.5°.

The optimal screw angle is the response variable that is most affected by gender, this because male and female pelvis anatomies are different. Examples of the main effects obtained in the design of experiments performed are shown in Figure 10. If a future cup design is required, the interaction between these angulations should be taken into account, given that this experiment portraits different types of anatomies and they all behave averagely as stated before.

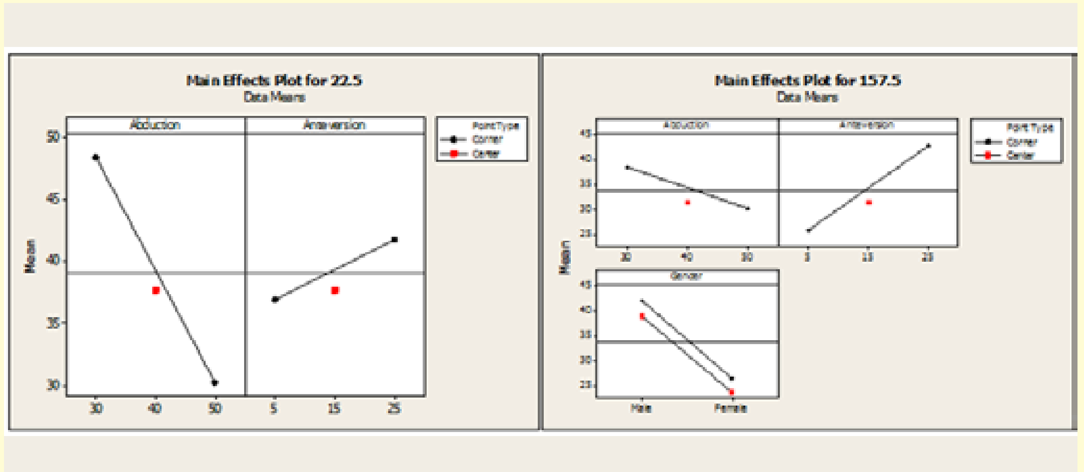

Figure 10 Main effect plots for 157.5°

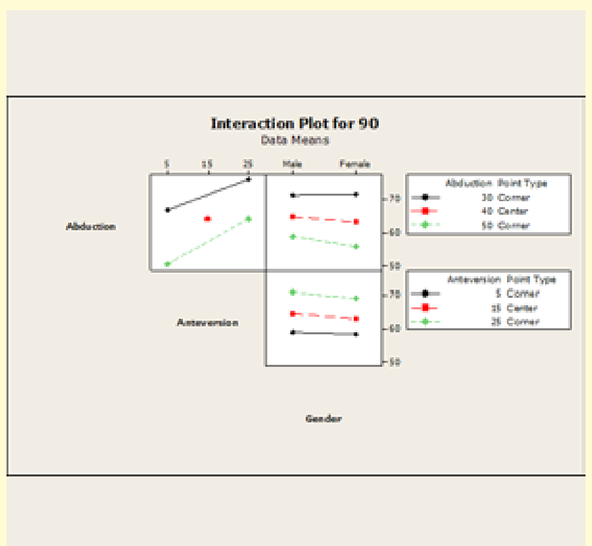

Figure 11 Interaction plot for 90°

In the analysis of the interactions the rotation angles with statistical significance, with any abduction angle and high values of anteversion (25°), the optimal angle increases. Regarding the gender differences, the main effects for each rotation were analyzed using an angle of abduction of 30° and maximum anteversion angle. The optimal screw angle increases for the majority of cases except for a rotation of 45° where female screw angle increases but male screw angle decreases instead. This means that in the rotation angles of 90°, 112.5°, 135°, 157.5° and 180° males would require a higher value for the screw angle.

Ji et al. [11] supported differences between gender however, the role of the gender factor is statistically significant for the optimal screw angle response variable. The viability of having cups designed specifically for either man or woman needs to be analyzed in terms of costs and manufacturing.

4. Conclusions

This study was based on the Dynasty® acetabular cup of Microport Orthopedics and because of this, there is no previous data based on 3D studies for this specific acetabular cup. Nevertheless some of the collected data can be used for future optimization of acetabular cups designs in the medical devices field.

The resulting data showed an opportunity of improving the angulation of the screw holes in the acetabular cup, to avoid risk structures as the sciatic nerve and also, prevent further dislocation or pain caused by a misguidedly positioned acetabular cup. The obtained data determined the optimal rotation to be used after abduction and anteversion angles have been chosen by the surgeon. The optimal abduction angle is between 30° - 40° and anteversion angles between 15° - 25° have proven to have better outcomes according to the results. However, rotation must always be kept between 0° - 45° or 112.5° - 157.5° from the Anterior Superior Iliac Spine, otherwise the statistical results show a higher chance of pelvis puncture.

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