Effects of Acetabular Cup Orientation and Implant Design on Psoas Impingement in Total Hip Arthroplasty

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Abstract

Background: Durable fixation has been demonstrated with use of large (jumbo) cementless cups in revision total hip arthroplasty (THA). However, anterior protrusion of the cup rim may impinge on the iliopsoas tendon and cause groin pain. The purpose of this study was to assess the effect of cup position and implant design on iliopsoas impingement.

Methods: THA was performed on six cadaver hips using oversized (jumbo) acetabular components, 60 to 66mm. A stainless steel cable was inserted into the psoas tendon sheath to identify the location of the psoas muscle. CT scans were performed on each cadaver and imported in an imaging software. The acetabular shells, cables, and pelvi were segmented to create separate solid models of each. The shortest distance between each shell and cable was measured. To determine the influence of cup inclination and anteversion, the inclination (30°/40°/50°) and anteversion (10°/20°/30°) angles were varied in the virtual model for both a hemispheric and offset head center shell design.

Results: The shell to wire distance increased linearly with greater cup anteversion ($R^2 > 0.99$) while inclination had less effect. The distance was greater for the offset head center cup in comparison to the hemispheric cup. Our results indicate that psoas impingement is related to both cup position and implant geometry.

Conclusions: For an oversized jumbo cup, psoas im-

pingement is reduced by greater anteversion while cup inclination has little effect. An offset head center cup with an anterior recess was helpful in reducing psoas impingement in comparison to a conventional hemispherical geometry.

Background

Total hip arthroplasty (THA) is a successful procedure with high survivorship and patient satisfaction. However, groin pain after THA has been reported in a subset of patients. The etiology is considered to be related to impingement between the iliopsoas tendon and anterior acetabular component [1-7]. As a result, iliopsoas tendonitis can be a considerable cause of pain and dissatisfaction in THA patients.

Psoas tendonitis after THA can be treated non-operatively with NSAID's, cortisone injections, and physical therapy [5,6]. However for patients with persistent symptoms surgery consisting of psoas tenotomy or revision THA is indicated [3,4,6,7].

Cup orientation and size can influence the risk of psoas impingement. Lewinnek defined the safe zone of acetabular cup placement with an inclination range of 30°-50° and anteversion range of 5°-25° [8]. Recently, the utility

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Level of Evidence: N/A (in vitro study)

of safe zone has been questioned, yet it continues to serve as a guide for cup placement in THA [9]. The ranges for both inclination and anteversion after THA are wide and can also be affected by spinal deformity [10]. Large acetabular cups which are typically used in revision THA have a greater surface area have more potential to cause psoas impingement. Odri et al reported that patients with cups greater than 6mm larger than the native acetabulum had a significant increase in groin pain after THA [2]. More anatomic implant designs have been developed including an anterior recess or bevel in the acetabular shell and anatomically contoured dual mobility femoral head to mitigate the risk of psoas impingement [7,11,12,13].

Clinically, groin pain has been used as a surrogate for potential psoas impingement. However, direct assessment of psoas impingement in patients is not straightforward and it may require advanced imaging techniques such as MRI or fluoroscopy imaging under dynamic loading conditions. The purpose of this study was to assess the effect of cup orientation and implant design on risk of psoas impingement in human cadavers using CT imaging to construct 3D models of the pelvis and soft tissue.

Materials

Three fresh frozen human cadavers were obtained to perform bilateral THA for this study, Table 1. Cadavers with an intact lumbar spine were used to preserve the anatomic origin of the iliopsoas muscle. The hip was exposed through a conventional posterior approach. The acetabulum was reamed using hemispherical reamers in 2mm increments with the goal of reaming the acetabulum to a diameter 10mm larger than the native acetabulum and maintaining the inferior edge of the reamer at the anatomic inferior acetabulum. Offset head center acetabular shells (Restoration Anatomic Shell, Stryker, Mahwah, NJ) were implanted in all cases (Figure 1). At least one fixation screw was used with each shell. The shell sizes used in this study were 60mm, 62mm and 66 mm as in shown

in table 1. The relatively large shell sizes were chosen to simulate THA revision cases. On the femoral side, tapered wedge primary stems (Accolade II, Stryker, Mahwah, NJ) were used in all cases. A 2mm diameter flexible stainless steel cable (Dall-Miles cable system, Stryker, Mahwah, NJ) was inserted into the psoas tendon sheath between the muscle and the surrounding membrane to identify the location of the psoas muscle radiographically (Figure 2). Additional sutures were used to secure the cable to

Figure 1: Offset head center acetabular shell which includes an anterior bevel in the rim of the implant (Restoration Anatomic Shell, Stryker, Mahwah, NJ).

Figure 2. (A) Photo illustrates a cable inserted into the psoas tendon sheath at the level of the lesser trochanter through a conventional posterior approach. (B) Fluoroscopic image demonstrates the position of the cable in the psoas tendon sheath in proximity to the inferior margin of the acetabular shell.

the distal psoas tendon to ensure that the cable remained attached to the psoas during the procedure and imaging.

Following the procedures, cadavers were sent for computed tomography (CT) imaging (CT parameters: 1 mm axial slices; 120-140 kV; 200-250 mA). The CT images were imported into the imaging software Mimics (Materialize, Belgium) for further analysis. The acetabular shells, cables, and pelvis were segmented to create distinct solid models of each. This was done to study the spatial relationship between the shell and cable, which was assumed to represent the position of the psoas tendon. Computer aided design (CAD) models of each shell were superimposed on the acetabular shells obtained from CT images. This allowed us to create clean models of the shells implanted in the solid models created from the CT scans. To compare the offset head center shell to a conventional hemispher-

Table 1: Demographics and implant sizes used in each cadaver

Specimen #	Age, Gender, BMI	Operated side	Acetabular cup size, mm
Specimen 1	62 yrs., F, 17.5	Left	64
		Right	62
Specimen 2	73 yrs., F, 26	Left	64
		Right	64
Specimen 3	84 yrs., F, 18	Left	60
		Right	60

Figure 3. (A) Solid model of the pelvis created using a typical CT scan. The offset head center shell (blue) and cable (red) are shown. (B) Solid model of the same pelvis where the offset head center has been replaced by a conventional hemispherical shell (Green).

ical shell in the same orientation, the offset head center shell was virtually replaced with an equivalent diameter hemispherical shell by overlaying the outer shell surfaces of both designs and keeping the faces of shells parallel, (Figure 3). This allowed analysis of the conventional hemispherical shells in the orientation identical to that of the offset head center shells. The shortest distance between each shell and cable was measured. To determine the influence of cup inclination and anteversion on psoas impingement, multiple inclination and anteversion angles were simulated. For both shell designs, three different inclination angles (30°/40°/50°) and three different anteversion (10°/20°/30°) angles were studied by virtually placing each shell in these orientations respectively. A positive distance value indicated clearance between the shell and the wire while a negative value indicated impingement. A linear regressions analysis was conducted to determine the correlation coefficient factor between the changes in cup anteversion/inclination angles and the level of impingement.

Table 2: Original orientation of shells implanted in each cadaver

Specimen #	Operated side	Original shell inclination/anteversion
Specimen 1	Left	44.65°/23.34°
	Right	41.71°/33.83°
Specimen 2	Left	40°/17°
	Right	31.68°/23.54°
Specimen 3	Left	32.97°/28.98°
	Right	46.69°/6.31°

Results

The original orientations of the offset head center shells are presented in Table 2. The effect of change in anteversion on both shell designs is depicted in figure 4. With the virtual implantation of both shell designs at orientations 40°/10°, 40°/20°, 40°/30° (inclination/anteversion) we found that greater anteversion decreased psoas impingement in both shell designs. For example, 40°/30° orientation resulted in no impingement in either shell design. The correlation factor was also very high ($R^2 > 0.99$) indicating a strong linear relationship between wire distance and shell anteversion angle.

Figure 5 illustrates the influence of inclination angle on shell to wire distances. When the influence of inclination angle on psoas impingement was analyzed by comparing wire distances for three orientations (30°/20°, 40°/20°, 50°/20°), the effect was less pronounced than anteversion. There was a trend for lower inclination angles to result in

Figure 4. Effect of increasing anteversion from 10 to 30 degrees on shell to wire distance for a fixed inclination value of 40 degrees. The vertical axis represents the closest distance (mm) between the cable in the psoas tendon and acetabular component for the offset cup (RAS) and hemispherical shell (Trident). A negative value indicates psoas impingement and positive value indicates clearance between the psoas and acetabular component.

less impingement, yet the correlation coefficient values were lower ($R^2=0.77$ for offset head center and $R^2=0.94$ for conventional design).

The delta between the wire distances for offset center and hemispherical shells were calculated for each specimen. For the offset center shells, the shell to wire distance in all cases was positive (range 0.07-3.44 mm) indicating that there was clearance between the shells and psoas. When the offset head center was replaced with the conventional hemispherical shell, the distance was negative (range: -1.32- 1.41) indicating psoas impingement in 3 out of 6 cases.

Discussion

Most acetabular defects encountered in revision THA have a distorted but expanded rim (Paprosky type 2) and can be treated with a large cementless cup and screw fixation [14]. Results of large (jumbo) cementless cups in revision THA have demonstrated durable long term fixation and implant survivorship [15,16]. A “jumbo” cup has been considered to be approximately 10 mm larger than the native acetabulum [16,17]. However, cup sizes 6mm or larger than the native acetabulum have been associated with an increase in groin pain which has been attributed to psoas tendonitis [2]. Since psoas tendonitis appears to be related to the amount of anterior overhang of the cup rim beyond the physiologic or anatomic bony rim, both cup size and implant position can affect the risk of psoas tendonitis.

Our findings indicate that cup anteversion has a direct effect on risk of psoas impingement while cup inclination has a less significant relationship. For the oversized hemispheric cups used in this study anteversion of 20 degrees or more was required to avoid cup impingement. However the cadavers used in this study were in the supine position and in vivo studies have demonstrated considerable change in the relative inclination and anteversion from supine to sitting to standing positions [18]. Patients with spinal disease or limited spine motion also have an increased risk of impingement and dislocation which suggests that this patient population would also have an increased risk of psoas impingement and tendonitis [19]. Other studies have questioned whether there is a “safe range” of cup position to avoid dislocation after THA [8]. These findings suggest

Figure 5. Effect of increasing inclination from 30 to 50 degrees on shell to wire distance for a fixed anteversion value of 20 degrees. The vertical axis represents the closest distance (mm) between the cable in the psoas tendon and acetabular component for the offset cup (RAS) and hemispherical shell (Trident). A negative value indicates psoas impingement and positive value indicates clearance between the psoas and acetabular component.

that while adequate anteversion may have a protective effect on mitigating the risk of psoas tendonitis there may not be a “safe range” of cup position to avoid psoas tendonitis, particularly with use of oversized “jumbo” cups.

The anatomic acetabular rim has an asymmetric contour which includes an anterior recess that the psoas tendon crosses, while acetabular components have traditionally been symmetric hemispheric or low-profile (slightly less than a hemisphere) shaped. The hemispheric acetabular component provides greater coverage of the femoral head while the low-profile cup geometry provides greater range of motion to impingement. More asymmetric implant designs have been developed to mitigate the risk of psoas impingement. Bousquet described use of an anatomic dual mobility cup in which the implant rim matches the anatomic contour of the native acetabulum with a cut out for the psoas tendon [20,21]. The Restoration Anatomic Shell, which was used in this study is intended to restore the anatomic head center and mitigate risk of psoas impingement with an anterior bevel in the rim of the component as an alternative to a hemispheric cup [12,13]. A similar result could be achieved with use of an augment above a cup which then avoids the anterior overhang of a larger hemispheric cup without an augment [22]. However this technique which requires two independently fixed implants can be technically challenging. Modification of the conventional hemispheric femoral head to an anatomic contoured dual mobility head may also reduce the risk of psoas impingement [11]. The advantage of implant designs such as those described above is that risk of psoas

impingement would appear to be improved independent of cup position. Our results indicate that use of a large diameter offset head center cup reduced risk of psoas impingement by an amount essentially equivalent to an increase in anteversion of a hemispheric cup of 10 degrees. However clinical studies will be necessary to determine if this implant design has the predicted clinical benefit of reducing symptomatic psoas tendonitis in vivo.

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AUTHOR DISCLOSURES

Cadaveric and implant materials, and laboratory testing facilities used for this study were provided by Stryker Orthopaedics.

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