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The Safe Zone for The Placement of Transacetabular Screws in Total Hip Arthroplasty using an *In Vivo* Three-Dimensional Analysis

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The Safe Zone for The Placement of Transacetabular Screws in Total Hip Arthroplasty using an *In Vivo* Three-Dimensional Analysis

Directed by Professor Kwan Kyu Park

Doctoral Dissertation
submitted to the Department of Medicine,
the Graduate School of Yonsei University
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

Jun Young Park

June 2021

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as me, my mother Bu Seon Lee and my younger sister and brother in my thesis. I also express my sincere gratitude to my father-in-law and mother-in-law who are always on my side and supports my life. Finally I give my precious heart of love and gratitude to my lovely wife Eun Jung Ko, MD., PhD. who always dedicate to my family, my daughter Ha Min Park and my son Geon Min Park who give me infinite happiness and joy that can't be replaced with anything in this world.

Based on the valuable experience gained during the preparation period for this thesis, I will do my utmost to become the orthopaedic doctor with a excellent medical ability and warm heart by working hard on a patient care and clinical research in the future.

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<TABLE OF CONTENTS>

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LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

The Safe Zone for The Placement of Transacetabular Screws in Total Hip Arthroplasty using an *In Vivo* Three-Dimensional Analysis

Jun Young Park

Department of Medicine
The Graduate School, Yonsei University

(Directed by Professor Kwan Kyu Park)

Introduction: Pelvic vascular injury caused by a transacetabular screw is rare, but a major local complication of total hip arthroplasty (THA). We aimed to obtain the anthropometric data about the safe zone by analyzing the three-dimensional (3D) reconstruction model and determine the safe length of transacetabular screws by performing the 3D simulated surgery.

Methods: 556 patients underwent lower extremities angiographic computed tomography (CT) scans in the single institution from November 2011 through March 2016 were retrospectively reviewed. In those, 25 patients met the inclusion criteria: middle-aged women with a normal hip

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joint, normal vascular status on CT findings, and no prior spine and lower extremity surgery history. We reconstructed the 3D models of 50 hips using the customized computer software. We measured the central angles of the posterior-superior (P-S) area and safe zone and the safe depth of the safe zone on the 3D reconstruction model. We performed a 3D simulated surgery using the customized implant to measure the safe transacetabular screw lengths.

Results: The measured central angle of the P-S area was 79.5°, which was less than the 90° angle in the classic quadrant system. We determined a mean safe depth of 49.8 mm in the safe zone, with a mean central angle of 47.7°. During the 3D simulated surgery, we determined a mean safe transacetabular screw length of 43.3 mm when applied to a lateral hole on a line bisecting the P-S area.

Conclusion: The quantitative measurements obtained in our study may help reduce the incidence of vascular injury during transacetabular screw fixation in THA.

Key words: *in vivo* 3D analysis, 3D reconstruction model, simulated surgery, THA, transacetabular screw fixation, safe zone, vascular injury

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I. INTRODUCTION

Transacetabular screw fixation is used widely to improve the initial stability of an uncemented cup, despite controversy[1-3]. Pelvic vessel injury caused by a transacetabular screw is a major local complication of total hip arthroplasty (THA)[4]. The incidence of pelvic vascular injury during THA ranges from 0.04% to 0.25%[5-7], and each orthopedic surgeon might encounter at least one such case every 14 years of clinical experience[8]. Despite the rare incidence of pelvic vascular injury, it is among the most serious and potentially fatal complications of THA[9-10]; affected patients may require additional surgical treatments such as laparotomy, vascular direct repair, amputation, or vascular bypass surgery[11-16].

The common iliac vessel is divided into the external and internal iliac vessels in front of the sacroiliac joint at the height of the pelvic brim. After the internal iliac

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vessel is divided from the common iliac vessel, it travels posteriorly to the greater sciatic foramen. The internal iliac vessel is divided into the anterior and posterior divisions at the level of upper border of the greater sciatic notch. The superior gluteal vessel of posterior division exits the pelvic cavity through the superior gap of the greater sciatic foramen. The obturator vessel is the branch of the anterior division of the internal iliac vessel. It travels forward along the inner side of the pelvic bone and passes through the obturator canal and exits the pelvic cavity. Particularly, the external iliac vessels and obturator vessels are vulnerable periacetabular vascular structures due to their proximity to the acetabulum[17,18].

Interest in additive manufacturing during total joint arthroplasty has increased recently[19]. Surgeons can use three-dimensional (3D) models to accurately analyze complex anatomical structures before the actual surgery and can also measure the geometry of the area of interest during a virtual surgery simulation[20]. Notably, 3D reconstruction models have a known spatial error of <1 mm[21]. Accordingly, 3D reconstruction models have become an important tool used by surgeons for the qualitative and quantitative evaluation of the pelvic bone and vessels[22,23].

The pelvic vessels are located behind the acetabulum, and their locations and distributions are impossible to recognize intraoperatively during THA[24-26]. Therefore, precise anthropometric measurements of the pelvic bone and vessels are required to confirm the safe region for the placement of transacetabular screws and thus reduce the risk of injury to these vessels. Historically, several cadaveric studies were performed to determine the safe region[25-29]. Based on the results of those studies, we have placed the transacetabular screw in the posterior-superior (P-S) quadrant while excluding the central area to avoid

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vascular injury. However, various reports of injuries to the blood vessels, and especially the arteries, continued to arise even after the concept of the quadrant system was introduced[10,13-15,30-32]. To date, several studies have used 3D models to investigate the periacetabular vasculature[33-35], but few have actually measured the safe zone in a 3D space. Our hypothesis is that measurement results of the safe zone obtained using 3D models will be different from the known quadrant system.

We aimed to obtain anthropometric data about the safe zone by analyzing the 3D reconstruction model and determine the safe length of transacetabular screws by performing the 3D simulated surgery. The pulposes of our study are : 1) to define the reference plane on the 3D reconstruction model to measure the parameters of the safe zone, 2) to elucidate the distribution and course of vasculatures around the safe zone, 3) to obtain the anthropometric data of the safe zone without risk of the pelvic arterial injury, and 4) to confirm the safe length of transacetabular screws in each hole of the customized cup implant by performing the 3D simulated surgery.

II. Materials and methods

1. Patients data collection

We retrospectively reviewed 556 patients who underwent lower extremities angiographic computed tomography (CT) scans in the single institution from November 2011 through March 2016. In those, 25 patients (50 hips) met the inclusion criteria: middle-aged women with a normal hip joint, normal vascular status on CT findings, and no prior spine and lower extremity surgery history.

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2. Reconstruction of 3D models (data acquisition and segmentation)

CT was performed from the 10th thoracic vertebral level to the bilateral feet. Patients were placed in the supine position, with their legs slightly externally rotated. A high-resolution CT scanner (SOMATOM Definition Flash, Siemens, Forchheim, Germany) at a 1-mm slice thickness was used. The patients were injected intravenously with the contrast medium iohexol (Omnipaque™, GE Healthcare, Cork, Ireland) through the cubital vein. The scanned image data of each patient were stored in the DICOM (Digital Imaging and Communications in Medicine; National Electrical Manufacturers Association, Rosslyn, VA, USA) format. The acquired DICOM files were imported into a customized software program (Mimics 19.0 software; Materialise, Leuven, Belgium). A thresholding technique is performed, which is considered one of the most objective methods for region highlighting[36]. We created a 3D reconstruction model of our target region (Figure 1 (a)).

3. Defining the acetabular cup plane in a pelvic reference frame

To measure the cup inclination and anteversion, we defined the anterior pelvic plane (APP) as the coronal plane[37]. The most ventral points within the anterior superior iliac spines (ASIS) and pubic tubercles were selected automatically in our 3D reconstruction images. The sagittal plane was defined as the plane perpendicular to both the APP and a vector passing through the bilateral ASIS points residing in the APP. The axial plane was defined as normal to both the coronal and sagittal planes (Figure 1 (b)).

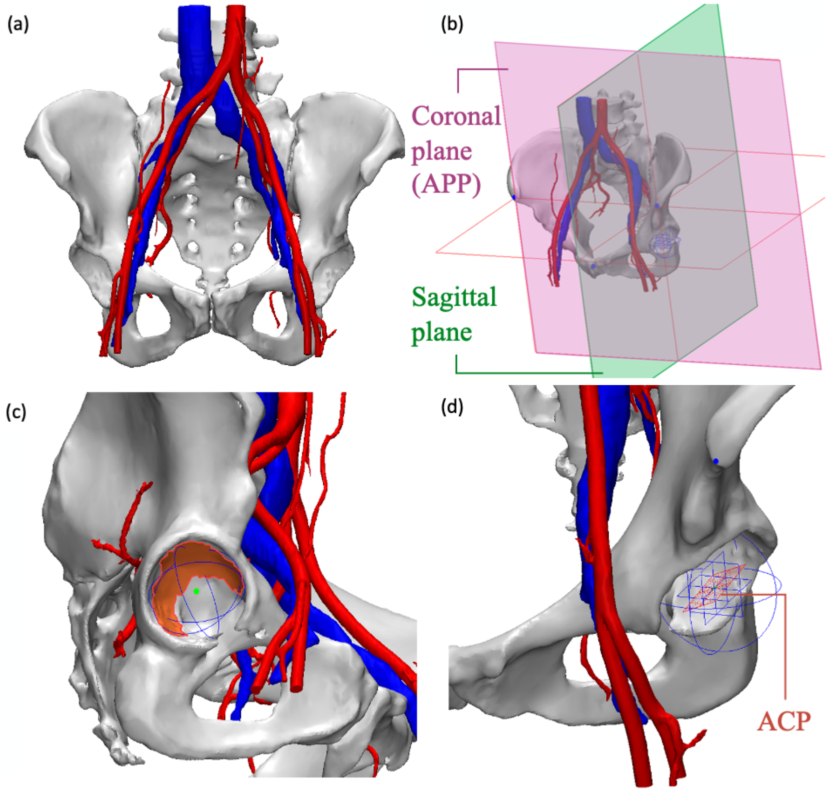

Figure 1. The pelvic reference frame and acetabular cup plane (ACP). (a) Three-dimensional reconstruction model of the pelvic bone and vasculature. (b) The system of coordinates based on the anterior pelvic plane (APP). (c) The center and radius of the acetabular cup determined to best fit the inner surface of the acetabulum. (d) The ACP is defined as 40° of the radiographic inclination and 15° of the radiographic anteversion relative to the APP.

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The acetabular cup was assumed to have a hemispheric shape, and the radius of the acetabular cup and the acetabular cup center (ACC) were determined individually to provide the best fit to the inner surface of the acetabulum (Figure 1 (c)). The orientation of the acetabular cup was defined as a 40° inclination and 15° anteversion in the radiographic angles relative to the APP[38, 39] (Figure 1 (d)). The acetabular cup plane (ACP) was defined as the plane perpendicular to the acetabular cup orientation vector. We measured the parameters of the periacetabular vasculatures based on the ACP because we assumed the ACP as the operator's view during the surgery. Line A was defined as the line extending from the ASIS to the ACC. Line B was defined as the line passing through the ACC and the tangent to the greater sciatic notch on the ACP (Figure 2 (a)). We designated the four areas separated by these two lines as the anterior-superior (A-S), posterior-superior (P-S), posterior-inferior (P-I) and anterior-inferior (A-I) areas (Figure 2 (b)).

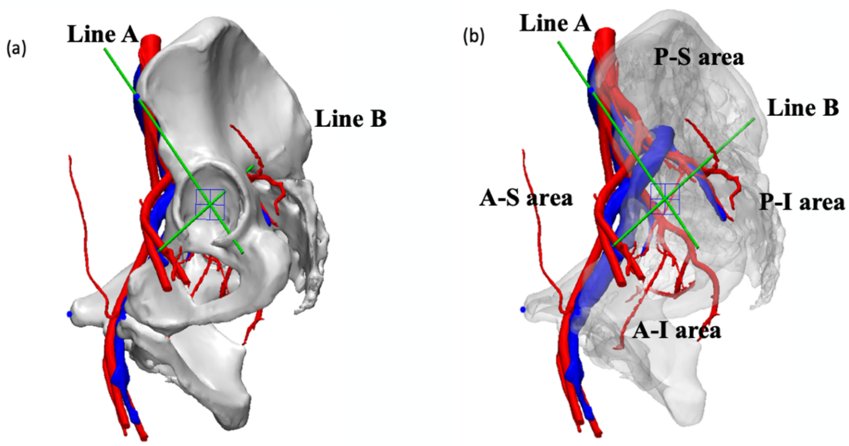

Figure 2. Separation of the acetabular cup plane (ACP). (a) Line A connects the anterior superior iliac spines to the acetabular cup center

(ACC), and Line B passes the ACC and is tangent to the greater sciatic notch. (b) Four areas on the ACP are separated by Lines A and B: anterior-superior (A-S), posterior-superior (P-S), posterior-inferior (P-I) and anterior-inferior (A-I).

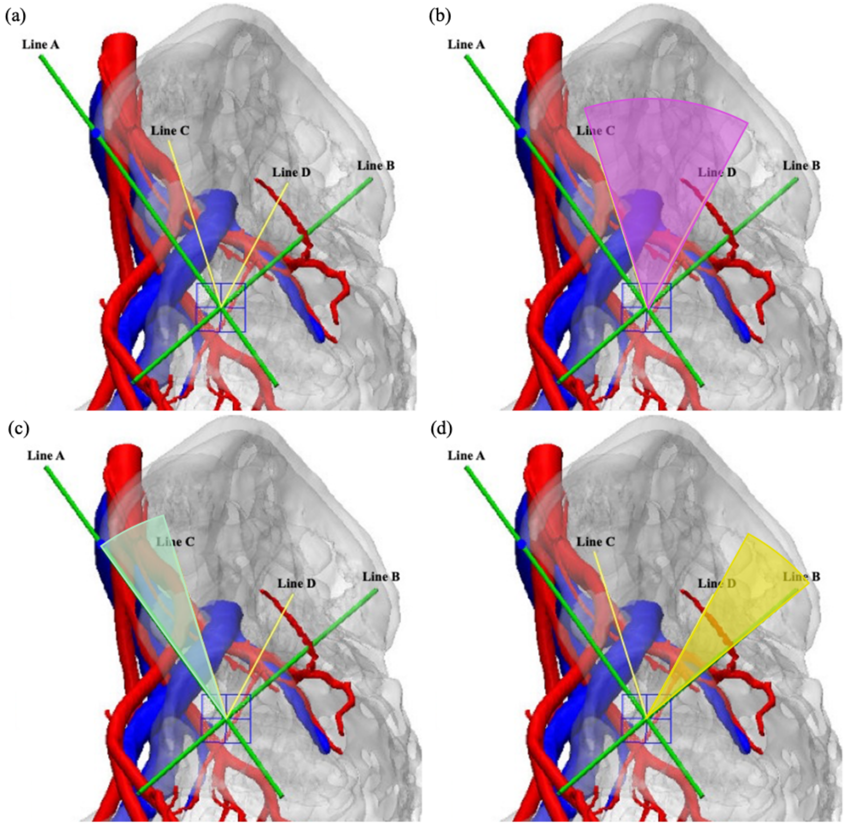

Figure 3. The safe zone and the danger zone. (a) Line C connects the most convex point of the external iliac artery (EIA) to the acetabular cup center (ACC), and Line D connects the origin of the obturator artery (OA) to the ACC. (b) The safe zone. (c) The danger zone of the EIA. (d) The danger zone of the OA.

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4. The central angle and safe depth of the safe zone

We measured the following three morphometric parameters on the ACP: the central angle of the P-S area, the central angle of the safe zone and the safe depth of the safe zone. We analyzed the arterial injury because arterial damage is associated with a relatively worse prognosis than venous damage, and the timing of venous phase imaging during CT angiography is unclear.

First, the central angle of the P-S area was defined as the angle between Lines A and B on the P-S area (Figure 3 (a)). Second, the most convex point for Line A was determined along the course of the external iliac artery (EIA) in the P-S area. Line C was defined as the line between this most convex point and the ACC. The danger zone of the EIA was designated as the section of the P-S area between Lines A and C (Figure 3 (c)). The central angle of the danger zone of the EIA was defined as the angle between Lines A and C on the P-S area. We classified the courses of the EIA in each hip into three types, straight, single-curved and tortuous double-curved, as described previously[33] (Figure 4).

Third, we confirmed that the reconstructed obturator artery (OA) was clearly distinguishable and that the origin of the OA originated in the anterior division of the internal iliac artery. Line D was defined as the line between the origin of the OA and the ACC. We designated a section of the P-S area between Lines B and D as the danger zone of the OA (Figure 3 (d)). The central angle of the danger zone of the OA was defined as the angle between Lines B and D on the P-S area. We defined the safe zone as a region of the P-S area excluding the two danger zones, which had no risk of injury to the two major pelvic arteries (Figure 3 (b)). The

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central angle of the safe zone was determined by subtracting the two types of central angles of the danger zone from the central angle of the P-S area.

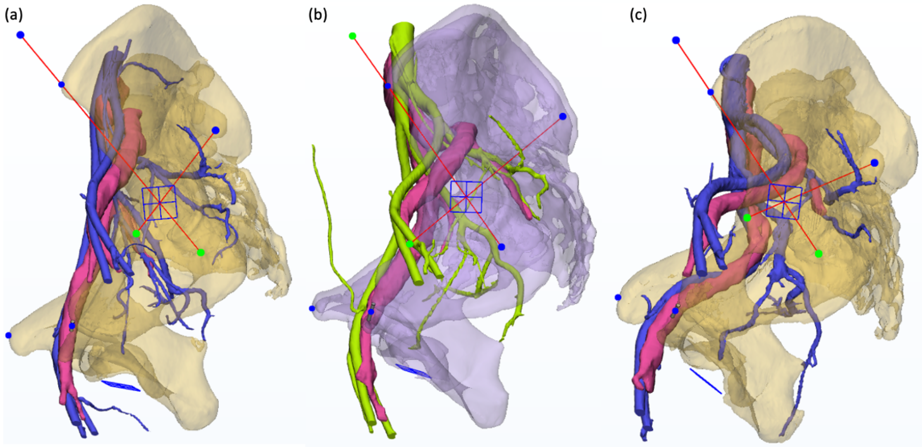

Figure 4. Types of external iliac artery courses: (a) straight, (b) single-curved, and (c) tortuous double-curved

Fourth, we measured the distance between the ACC and the branching point of the superior gluteal artery in the 3D space (Figure 5 (a)). The safe depth of the safe zone was defined as the difference between the radius of the acetabular cup and distance from the ACC to the branching point of the superior gluteal artery (Figure 5 (b)).

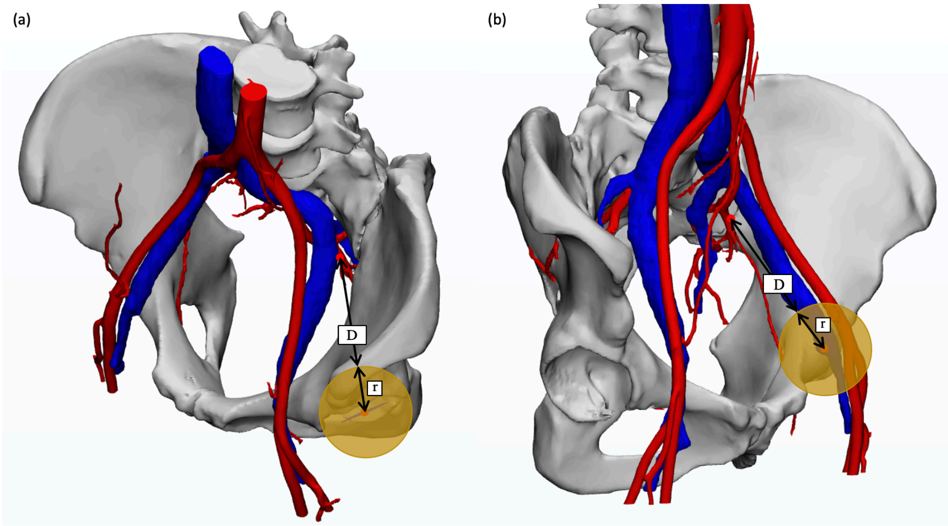

Figure 5. The safe depth of the safe zone. (a) Measured distance between the acetabular cup center and the branching point of the superior gluteal artery. (b) Inner view of the measurement.

D, the safe depth of the safe zone; r, the radius of the cup.

5. 3D simulated surgery

We performed a 3D simulation of the transacetabular screw insertion using the customized cup implant. The implant contained one lateral hole and two medial holes (anterior and posterior), placed at a specific angle (Figure 6 (a)). We positioned the lateral hole on a line bisecting the P-S area to determine the rotation of each of the three holes (Figure 6 (b)). We assumed that the screw would be inserted perpendicularly and provisionally into each hole. We defined the safe length of the transacetabular screw as the distance from the screw hole of the cup to the inner surface of the pelvic bone. As the straight line from the ACC

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to each hole was perpendicular to the plane that contacted the hemisphere, we calculated the safe length of the transacetabular screw by subtracting the radius of the cup from the distance between the ACC and the quadrilateral surface of the pelvic bone (Figure 6 (c) and (d)). The safe lengths of the screws were measured in the lateral, medial anterior, and medial posterior holes.

6. Statistical analyses

R software, version 3.6.2 was used for statistical analyses. All data are presented as means, standard deviations, and ranges. The Mann–Whitney U test was used to compare the parameters between two groups according to the course of the OA. The one-way analysis of variance was used to compare the values of the safe lengths of the transacetabular screws among the three holes in the acetabular cup. A p-value <0.05 was considered to indicate statistical significance.

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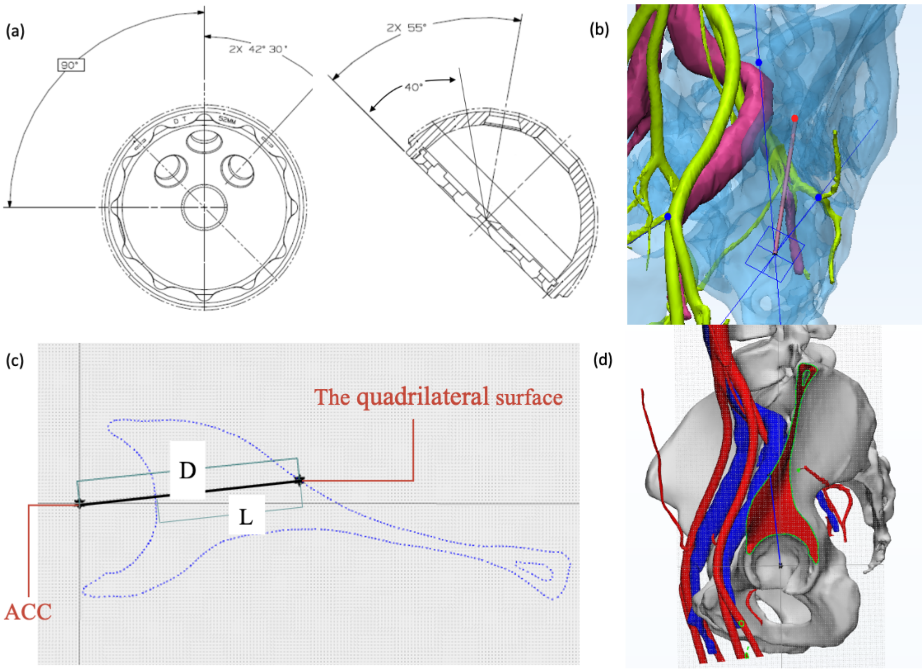

Figure 6. Three-dimensional (3D) simulated surgery. (a) Drawing of the customized acetabular cup implant. (b) Determination of the rotation of the location of holes on the acetabular cup plane. (c) Measurement of the safe length of the transacetabular screw. (d) Method of obtaining the plane with the transacetabular screw on 3D models.

L, the safe length of the transacetabular screw; D, the distance between the acetabular cup center (ACC) and the quadrilateral surface of the pelvic bone

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III. Results

Overall, the patients had a mean age of 46.0 ± 3.1 years and a mean body mass index of 22.8 ± 2.8 kg/m^2. All patients were Korean women. The mean diameter of the assumed acetabular cup was 45.8 ± 2.6 mm. Fourteen hips (28%) were classified as type 1 (straight), 25 (50%) as type 2 (single-curved) and 11 (22%) as type 3 (tortuous double-curved; Table 1).

Table 1. Demographics of the study cohort

Characteristics		Value
Numbers of hips		50
Age		46.0 ± 3.1 (40-50)
Height		159.0 ± 3.9 (150.0-167.0)
Weight		57.6 ± 7.6 (42.6-75.7)
BMI		22.8 ± 2.8 (17.6-29.8)
Diameter of the assumed acetabular cup		45.8 ± 2.6 (40.0–52.6)
	Type 1	14 (28%)
Course of the EIA	**Type 2**	25 (50%)
	Type 3	11 (22%)

BMI, body mass index; EIA, external iliac artery

Units of diameter of the assumed acetabular cup was millimeters.

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1. Distribution and courses of the periacetabular vasculature

The external iliac vessels and branching point of the superior gluteal artery were created clearly in our 3D reconstruction models of all 50 hips. The internal iliac vein and terminal branches of the internal iliac artery were not created because these vessels did not retain sufficient contrast medium for reconstruction. The OA was created distinctly in the 3D models of 42 hips. The courses of the periacetabular vasculatures on the ACP shared three common characteristics. First, a common iliac bifurcation was observed in the superior portion. Second, the EIA traveled from the bifurcation to the A-S area in one type among three: straight, single-curved, and tortuous double-curved. Third, the internal iliac artery split into anterior and posterior divisions; the posterior division became the superior gluteal artery and passed the upper margin of the greater sciatic notch (Figure 7).

However, two types of variations were observed in the course of the OA. In 34 hips (81%), the OA traveled from the origin to the A-I area and did not cross over Line D. However, in eight hips (19%), the OA crossed over Line D (Figure 8). Our definition of the danger zone of the OA could not be applied in this latter crossover group because the OA passed within the true safe zone. Therefore, we measured the angle between Lines B and D in the crossover group. The mean angle between Lines B and D was 48.6 ± 3.0° in the crossover group, significantly higher than that in the no-crossover group (Table 2).

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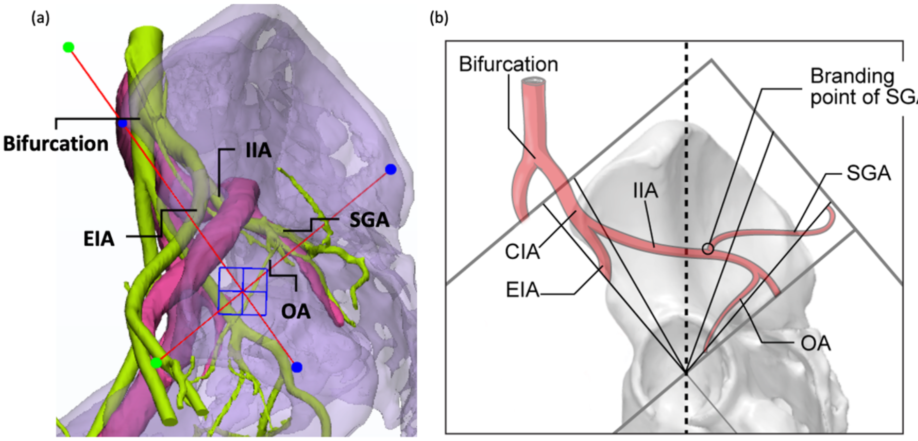

Figure 7. Common characteristics of the courses of the periacetabular vasculature on the acetabular cup plane (ACP). (a) Distribution of the periacetabular vasculature on the ACP. (b) Schematic drawing of (a).

CIA, common iliac artery; EIA, external iliac artery; IIA, internal iliac artery; OA, obturator artery; SGA, superior gluteal artery

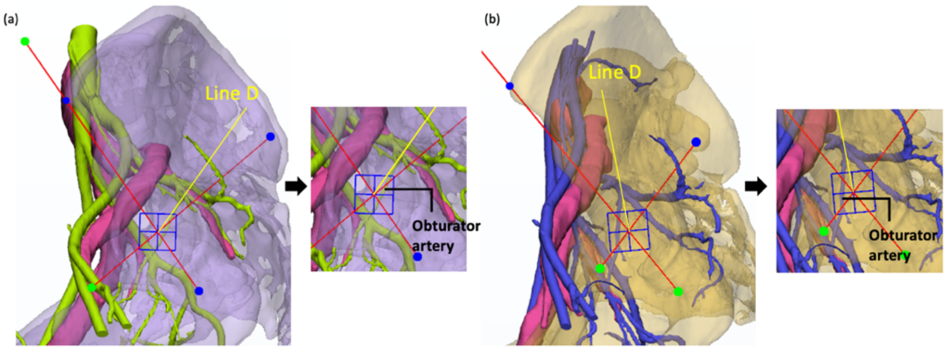

Figure 8. Variations of the obturator artery course: (a) no-crossover and (b) crossover

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Table 2. Comparison between the two groups according to the course of the obturator artery

		No-crossover (n=34)	Crossover (n=8)	*p*-value
Central angle	**P-S area**	80.6 ± 10.1 (61.8-100.2)	77.8 ± 7.4 (65.3-88.3)	0.396
	Danger zone of the EIA	11.8 ± 9.9 (-9.7-45.1)	10.2 ± 8.8 (-8.0-17.9)	0.936
Angle between the Line B and D		21.2 ± 13.9 (-16.0-41.7)	48.6 ± 3.0 (45.6-51.1)	< 0.001
Diameter of the assumed acetabular cup		45.8 ± 1.8 (42.8-50.1)	44.8 ± 3.2 (40.1-49.1)	0.532

Negative values of the central angle of the danger zone of the EIA means the Line C was on the anterior-superior area. Negative values of the angle between the Line B and D means the Line D was on the posterior-inferior area. The unit of the diameter of the assumed acetabular cup was millimeters.

P-S, posterior-superior; EIA, external iliac artery

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2. Central angle and safe depth of the safe zone (Table 3)

We measured the central angle of the danger zone of the OA, central angle of the safe zone and safe depth of the safe zone only in the 34 hips in the no-crossover group, as the definitions of the safe zone and the danger zone of the OA could not be applied to the eight hips that lacked reconstructed OA and the eight hips in the crossover group. The mean central angle of the P-S area was 79.5 ± 9.3° (range: 61.8-100.2). The mean central angle of the danger zone of the EIA was 10.1 ± 9.6° (range: -9.7-45.1). The mean central angle of the danger zone of the OA was 21.2 ± 13.9° (range: 13.9-32.9). The mean central angle of the safe zone was 47.7 ± 15.3° (range: 33.0-58.6). The mean safe depth of the safe zone was 49.8 ± 6.8 mm (range: 45.7-51.6).

3. 3D simulated surgery using the customized cup implant (Table 4)

The mean safe lengths of the transacetabular screws in the lateral, medial anterior, and medial posterior holes were 43.3 ± 5.0 mm (range: 33.3–55.1 mm), 8.2 ± 1.9 mm (range: 5.3–16.8 mm), and 19.8 ± 3.2 mm (range: 11.1–26.9), respectively. The safe length in the lateral hole was significantly larger than those in the other holes. (Figure 9).

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Table 3. Central angle and safe depth of the safe zone

Central angle				Safe depth of the safe zone*
P-S area	Danger zone of the EIA	Danger zone of the OA*	Safe zone*	
79.5 ± 9.3 (61.8–100.2)	10.1 ± 9.6 (-9.7–45.1)	21.2 ± 13.9 (13.9–32.9)	47.7 ± 15.3 (33.0–58.6)	49.8 ± 6.8 (45.7–51.6)

*: These parameters were measured in 34 hips because the OA in 8 hips were not completely reconstructed and the courses of the OA of the other 8 hips crossed Line D.

Negative values of the central angle of the danger zone of the EIA means the Line C was on the anterior-superior area. The unit of the safe depth was millimeters.

P-S area, posterior suprerior area; EIA, external iliac artery; OA, obturator artery

Table 4. Safe lengths of transacetabular screws

Medial anterior hole	Lateral hole	Medial posterior hole
8.2 ± 1.9 (5.3–16.8)	43.3 ± 5.0 (33.3–55.1)	19.8 ± 3.2 (11.1–26.9)

The unit of the safe length was millimeters.

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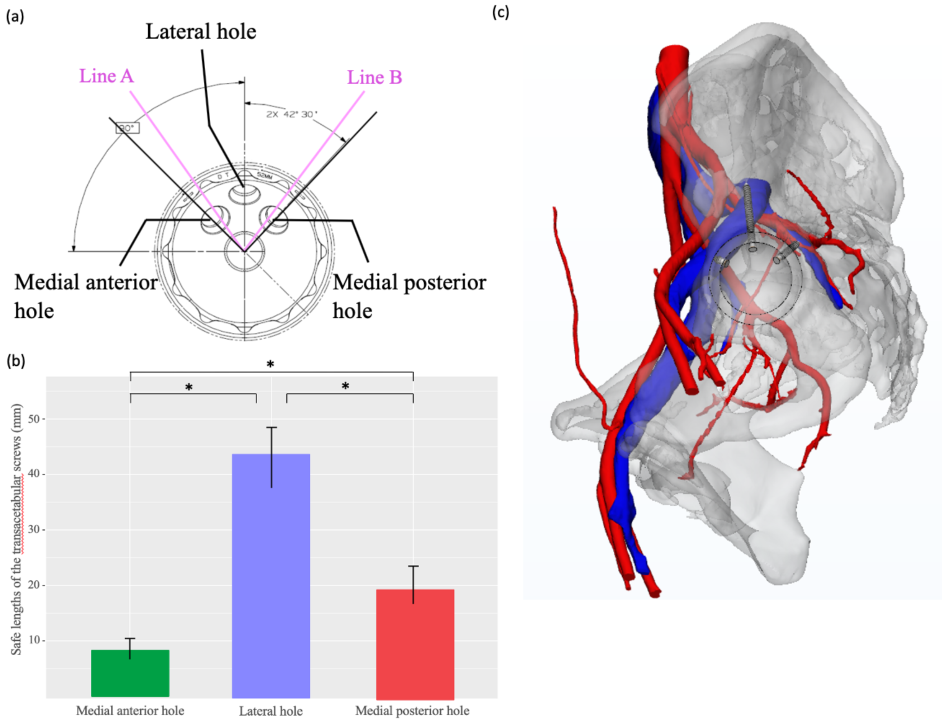

Figure 9. Results from the three-dimensional (3D) simulated surgery. (a) Location of each hole. (b) Bar plot of the safe lengths. There were significant differences among the safe lengths in three holes. (c) Transacetabular screw fixation on 3D model.

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IV. Discussion

We aimed to elucidate the ranges of the angles and depths of the safe zone for transacetabular screw fixation during THA. Using *in vivo* 3D reconstruction models, we concluded that the mean central angle of the P-S area on the ACP was 79.5°, much smaller than the 90° angle in the quadrant system[27]. We also defined a safe zone that excluded the risk of injury to the EIA and OA and revealed that the mean central angle and safe depth of the safe zone were 47.7° and 49.8 mm, respectively. The measured central angle of our new safe zone was 53% smaller than the 90° angle in the classic quadrant system and 47% smaller than the 79.5° angle measured in the P-S area in our 3D reconstruction models. Our 3D simulated surgeries using the customized cup implant revealed that the mean safe length of the transacetabular screw was 43.3 mm in the lateral hole, indicating that a screw with a maximum length of approximately 40 mm could be inserted into the lateral hole. Moreover, the mean safe length of the transacetabular screw was greater in the P-S area than in the A-S and P-I areas.

The EIA is the most frequently injured vascular structure during THA[10,16]. Although the frequency of OA injury is relatively low[10], this vessel travels near the inner wall of the acetabulum. In all 3D reconstruction models, we confirmed that both the EIA and OA traveled on the P-S area, which was known to be safe. Accordingly, we defined the safe zone more accurately by excluding the danger zones of the two arteries from the classic safe zone reported by Wasielewski[27]. The mean central angles of the danger zones of the EIA and OA were approximately 10° and 20°, respectively, while the central angle of the safe zone was approximately 50°; the safe depth of the safe zone was approximately 50 mm (Figure 10).

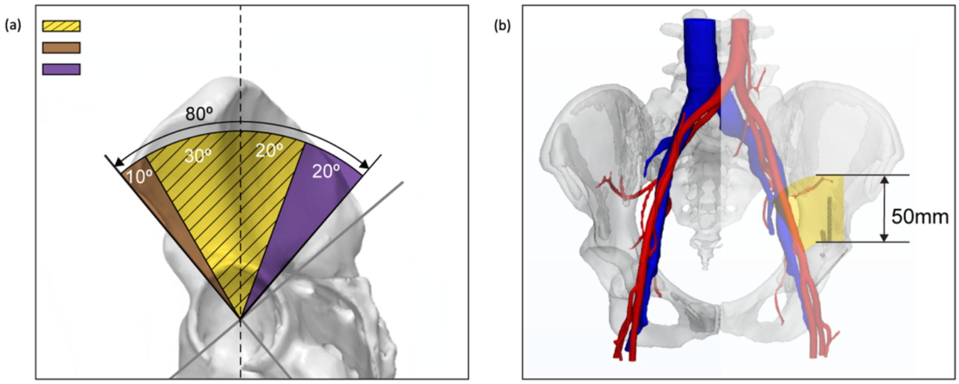

Figure 10. Schematic diagram of the safe zone. (a) The central angle of the safe zone was approximately 50° and the posterior-superior area was 80°. (b) The safe depth of the safe zone was approximately 50mm.

Yellow : Safe zone, Brown : Danger zone of the external iliac artery, Purple : Danger zone of the obturator artery

Our results of the positional relationship were derived from the ACP, which is a two-dimensional (2D) plane. We assumed that during surgery, the operator would directly view the acetabular cup, which would be oriented in an optimal position. Therefore, we recommend that operators use our guideline only if their view coincides with the ACP during surgery. We considered it easy to recognize the approximate location of the P-S area during the actual surgery, as the ASIS is an easily identifiable landmark and the P-S area would appear as an open plane with a central angle of approximately 80° between Lines A and B.

연세대학교
YONSEI UNIVERSITY

Many variations of the course and origin of the OA have been identified[40-43]. In eight hips (19%), the OA ran more anteriorly, crossed over Line D, and passed inside the safe zone. This variation occurred only when the angle between Lines B and D exceeded 43°. Previous cadaveric studies have suggested that damage to the obturator vessel may occur when inserting the screw into the polar area of the acetabular cup[27,44]. Although we suggested a safe zone wherein the OA has been excluded, we recommend avoiding the insertion of screws into the polar position of the acetabular cup, given the risk of the polar area and the variability of the OA.

We also considered the risk of injury to the superior gluteal artery on the safe zone, as this is the largest artery among the anterior and posterior divisions of the internal iliac artery[45]. The distance from the cup surface to the branching point of the superior gluteal artery was defined as the maximum screw length that would not create a vascular injury on the safe zone. Several studies have used 2D CT or cadavers to measure the distance between the pelvic bone and blood vessels[24-27,29,33,44,46]. However, the benefits of our simulation study include the free formation of virtual planes and the easy measurements of distances and angles in a 3D space.

The bisecting line used to determine the rotation the holes in our 3D simulated surgery was within the P-S area, and the mean safe length in the lateral hole was 43.3 mm. Therefore, we concluded that it would be safe to insert a transacetabular screw with a length of 40 mm into a lateral hole located on the bisecting line (Figure 11). The medial anterior hole of the cup was located in the A-S area; the corresponding mean safe screw length was 8.2 mm. This was consistent with a previous cadaver study that reported the bone depth of the

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anterior pelvic brim was 6–12 mm[27]. Wasielewski also reported that screws longer than 20 mm that were inserted along the rim of the posterior column were positioned near the sciatic nerve[27]. In our simulation, the medial posterior hole was placed on the P-I area, and the mean safe screw length in this hole was 19.8 mm. Thus, screws longer than 20mm could be dangerous on the P-I area.

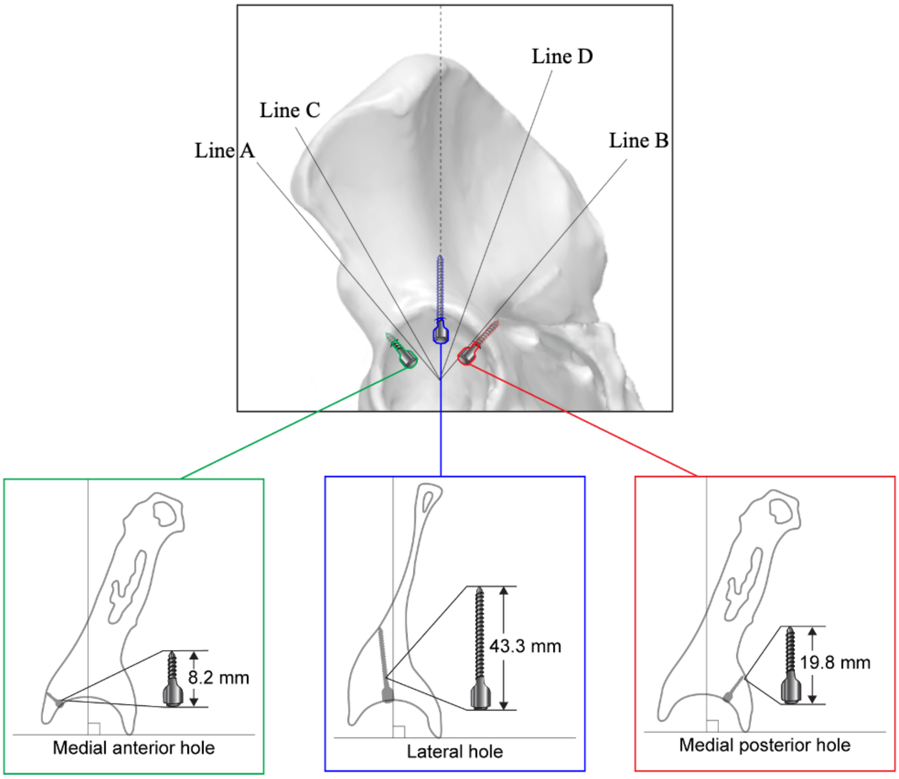

Figure 11. Schematic diagram of safe lengths of the transacetabular screws. The blue screw through the lateral hole was on the posterior-superior area. The green screw through the medial anterior hole was on the anterior-superior area. The red screw through the medial posterior hole was on the posterior-inferior area.

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It is difficult to measure the value of a 3D structure precisely when using a 2D image of the target. Such attempts might yield some degree of inaccuracy. Riten et al. used an intricate mathematical formula to determine the anteversion of a cup from plain radiographs[47]. However, a 3D reconstruction model can provide more precise anthropometric data about anatomical structures than 2D images[48,49]. Our study results present hip surgeons with meaningful quantitative data regarding the safe zone for the placement of transacetabular screws, especially in an optimally orientated acetabular cup. We can also use 3D computer programs to control the variables of the coordinate system and achieve consistent results. The APP used in our study has been set as the standard reference plane in many other 3D studies of the acetabulum[50,51]. A reference frame based on the pelvis is independent of the body position relative to the ground[39].

The recently introduced robot-assisted arthroplasty has been widely used to enable accurate implant positioning and alignment. Robot-assisted arthroplasty systems allow intraoperative inclination and anteversion of the acetabular cup in real time. Our results on the safe zone are expected to provide a meaningful guideline for reducing the periacetabular vessel injury risk during robot-assisted arthroplasty.

We acknowledge several limitations of our study. First, our sample included only middle-aged Korean women without apparent hip pathology. However, the muscles surrounding the hip joint have been reported to be smaller in osteoarthritis patients than in healthy controls[52,53]. Moreover, the anatomy of the periacetabular structures may differ between Asian and Caucasian populations. Accordingly, hip joint abnormalities such as a lower obturator internus muscle

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volume could lead to variations in the pelvic vessel course and distribution[24]. Second, our sample size was small. However, it required considerable time and effort to reconstruct the 3D vascular models. Third, the determination of the coronal plane in our reconstruction models may have introduce bias. We used the APP to define the coronal plane and align the cup to the optimal angle. The APP was defined as a plane connecting three anatomical bony landmarks. Our bias with respect to determining both the ASIS and pubic tubercles may have affected the reproducibility of determining the APP. Fourth, we did not analyze the risk of pelvic vein injury. Some branches of the internal iliac veins (superior gluteal vein, obturator vein, inferior gluteal vein and internal pudendal vein) were not completely reconstructed for each 3D reconstruction model because the timing of imaging in the venous phase was unclear. Finally, our study data was subject to the innate limitations of a 3D reconstruction method. The inherent inaccuracy of 3D studies according to the modification process has been criticized[35,54,55].

V. Conclusion

In conclusion, we presented a guideline for transacetabular screw fixation during THA. The maximum central angle of the safe zone was approximately 50°, with a depth of approximately 50 mm. The central angle of the P-S area was approximately 80°, much smaller than the 90° angle proposed in the classic quadrant system. A transacetabular screw with a maximum length of 40 mm could be inserted safely in a lateral hole placed on a line bisecting the P-S area. Although our study was limited by the use of a virtual computer program, the quantitative measurements obtained can help reduce the incidence of pelvic vascular injury during transacetabular screw fixation.

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연세대학교
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ABSTRACT (IN KOREAN)

인공 고관절 전치환술에서 경비구컵 나사못 삽입의 안전 구역에 관한 생체 3차원 분석 연구

<지도교수 박 관 규>

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박 준 영

연구 배경 및 목적: 경비구 나사못 삽입 시 발생하는 골반 내 혈관 손상은 인공 고관절 치환술의 주요한 국소 합병증으로 알려져 있다. 나사못 삽입의 안전 구역에 대한 인체계측학적 분석은 몇가지 카데바 연구만을 통해 시행되어 온 바 있다. 우리는 3차원 재건 모델을 이용하여 안전 구역에 대한 계측 데이터를 얻고 상품화된 비구컵을 이용한 3차원 가상 수술을 시행하여 골반내벽을 뚫지 않도록 하는 나사못의 안전 길이에 대해 알아보고자 한다.

연세대학교
YONSEI UNIVERSITY

연구 재료 및 방법: 2011년 11월부터 2016년 3월에 시행한 중년 한국인 여성 25명(50개의 비구)의 하지 혈관조영 컴퓨터 단층촬영 데이터를 이용하여 3차원 재건 모델을 만들었다. 이 모델에서 안전 구역과 후상방구역의 중심각을 측정하고 안전 구역의 깊이를 측정하였다. 3개의 나사못 구멍을 가진 상용화된 비구컵을 이용하여 경비구 나사못의 안전 길이를 측정하고자 3차원 가상 수술을 시행하였다.

연구 결과: 안전 구역의 중심각은 47.7도였고 최대 안전 깊이는 49.8mm였다. 후상방구역의 중심각은 79.5도로 고전적인 4구획 체계의 90도보다 작았다. 3차원 가상수술에서 후상방구역을 이분하는 선에 위치한 외측 나사못 구멍에서 측정한 경비구 나사못의 안전길이는 43.3mm였다.

결론: 3차원 재건 모델에서의 계측을 통해 고전적인 개념보다 더 정확한 안전구역을 밝혔다. 상용화된 비구컵의 외측 나사못 구멍에서 나사못의 안전길이가 약 40mm까지 확보됨을 확인하였다. 본 연구는 컴퓨터 프로그램 내에서 시행한 연구라는 한계점이 있지만 그럼에도 본 연구에서 얻은 몇가지 정량화된 결과치는 경비구 나사못 삽입 시 혈관 손상을

연세대학교
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줄이는데 도움이 될 것으로 생각된다.

핵심되는 말: 생체 3차원 분석, 3차원 재건 모델, 가상 수술, 인공 고관절 치환술, 경비구 나사못 삽입, 안전구역, 혈관 손상