Possible Vascular Injury Due to Screw Eccentricity in Minimally Invasive Total Hip Arthroplasty

Abstract
Background: Vascular injury during minimally invasive total hip arthroplasty (THA) is uncommon, yet a well-recognized and serious issue. It emerges because of non-visibility of vascular structures proximal to the pelvic bone during reaming, drilling holes, and fixing of screws. Numerous studies have found that screw fixation during cementless THA is beneficial for the initial stability of cup; yet, no anatomical guidelines support angular eccentric screw fixation. Materials and Methods: In this study, we obtained the pelvic arterial-phase computed tomographic data of thirty eight humans and reconstructed the three-dimensional models of osseous and vessel structures. We performed the surgical simulation to fix these structures with cementless cups and screws with angular eccentricities. Results: The effect of screw eccentricities (angular eccentricities of ±17° and ±34°) on the vascular injury was determined. Measurement between screw and adjoining vessels was performed and analyzed statistically to ascertain a comparative risk study for blood vessels that are not visible during surgery. Conclusion: Authors similarly discussed the significant absence of appreciation of quadrant systems proposed by Wasielewski et al. on eccentric screws. Adjustment of quadrant systems provided by Wasielewski et al. is required for acetabular implants with eccentric holes for fixation of acetabular screws.

Keywords: Acetabular cup, eccentricity, minimally invasive total hip arthroplasty, screw fixation, vessel injury
MeSH terms: Replacement, arthroplasty, hip, bone screws, acetabulum

Introduction

Incidence of minimally invasive total hip arthroplasty (MI-THA) has been increasing for the past 25 years in orthopedics as a result of the rapid upgrade of materials and instrumentation.1,2 During MI-THA, laceration of major blood vessels during fixation of the screw has been reported.3-8 However, fixation of the screw is a critical procedure: Correct alignment of a sized screw placed in the right direction and position will avoid vascular injury.8,9

In recent years, manufacturers are providing the eccentric hole on cup (up to 34°); screw fixation into this could result in vascular injury abiding the anatomical guidelines proposed by Wasielewski et al.9

Therefore, the goal of this study is to obtain spatial information of angular screw eccentricity that affects the vascular structure’s proximity to pelvis bone and possible angular screw eccentricity which is tolerable and for due consideration.

Materials and Methods

Data acquisition

For our study, we obtained the angiographic computed tomography (CT) image pelvic data of thirty eight patients (24 men, 14 women) from the Radio Diagnosis and Imaging department of our institute. The informed consent was obtained from all patients. All patients were scanned with a 64-slice spiral CT scanner (GE Medical Systems, USA), and 80 ml of omnipaque iohexol was injected intravenously by a high pressure injector through the cubital vein as a contrast medium. Scanning conditions were predefined as follows: 120 kV, 270 mA, 0.625 mm slice thickness with 1 mm spacing, scanned region: third lumbar vertebra to mid of femur bone and subsequent reconstruction distance of 1 mm. The reconstructed data were stored in .dicom format.

Three-dimensional model reconstruction

Volumetric data were transferred to medical imaging and editing software Mimics 18.0

Nishant Kumar Singh, Sanjay Kumar Rai, Amit Rastogi1
School of Biomedical Engineering, Indian Institute of Technology (Banaras Hindu University), 1Department of Orthopaedics, Institute of Medical Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Address for correspondence:
Dr. Sanjay Kumar Rai,
School of Biomedical Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, Uttar Pradesh, India.
E-mail: skrai.bme@iitbhu.ac.in

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Surgical simulation and measurements

Creo Parametric 3.0 software (PTC, Inc., Massachusetts, USA) was used to create the 3D model of a proper-sized acetabular cup, and the design of a commercially available acetabular cup with 12 screw holes (Pinnacle, Depuy, Warsaw, IN, USA) was used as a template.

For simulating clinical surgery, acetabular position is adjusted in orthographic coronal and sagittal planes at a level of true acetabulum, oriented at 45° of inclination with 15° and 20° of anteversion [Figure 2]. To achieve interference rim fit in reamed acetabulum, we positioned the inferior rim of the cup at the level of the bottom of teardrop line together with cup constraining in both anterior and posterior columns in the transverse plane.

Using a simple acetabular-quadrant system as described by Wasielewski et al., we divided the cup by two perpendicular lines. The first (line A) joined the anterosuperior iliac spine to the center of the acetabulum, resulting in an anterior and posterior halves. The second (line B), perpendicular to the first line (line A), also passed through the center of the acetabulum to create superior and inferior hemi-quadrants [Figure 1].

However, to mimic 3D screws, we created 13 standard 25 mm long screws (4 mm inner diameter and 5 mm outer diameter) and placed in each cup hole of all 38 hips using simulated screw fixations with ideal (screw fixed perpendicular to cup surface) and angular eccentric profiles. Screw configuration profiles (SCP) are listed in Table 1 and all possible angular eccentricities from the manufacturer guideline were demonstrated. Each cup was simulated with 12 screws and one polar screw. Further, each screw was rotated in accordance with developed SCP [Table 1]. Fixation of all 12 screws were performed according to their SCP [Figure 3A-E], whereas for polar screw, fixations were made along with subsequent SCP (1–5) as shown in Figure 3F, but it is quite not imaginative in figure so described below as:

SCP-1: In ideal screw fixation, polar screw’s axis was lying on the fixed acetabular axis passing through the geometric center of the acetabular cup [Figure 3A].

SCP-2: For polar screw, angular eccentricity is along acetabular axis plane (AXP), toward acetabular plane (AP) inferiorly [Figure 3F].

SCP-3: For a polar screw, angular eccentricity is along AXP, toward AP superiorly [Figure 3F].

SCP-4: For a polar screw, angular eccentricity is along the plane perpendicular to AXP and toward AP posteriorly [Figure 3F].

SCP-5: For a polar screw, angular eccentricity is along the plane perpendicular to AXP and toward AP anteriorly [Figure 3F].

To estimate the relative risk of different eccentric profiles of the screws on blood vessels proximal to pelvic bones, we used analysis tool in Creo Parametric at each level to measure the distance between screw and adjoining blood vessel. We then calculated the contiguous mean distance and their standard deviation from the major blood vessels such as obturator artery, external iliac vein, external iliac artery, inferior gluteal artery, and superior gluteal artery to its adjacent screws in all the 38 patients.

Initial criteria were setup to consider the risk factor of vessels

C1 - Structures were entirely safe if, they were at a distance >20 mm from the screw.

C2 - Structures were considerably safe if screw tip was not directed to blood vessels with a distance >5 mm.

C3 - Structures were considered at risk if, they felt within 5–20 mm from the screw and screw tip was directed to
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blood vessels (The criterion takes into normal anatomical variation plus change in vascular structure position due to hip movement).

C4 - Structures were considered fully insulted if they were hit and punctured by the screw, or structures that touched the tip of screw and/or having a distance <5 mm.

However, we consider that the screws, which lie inside the bone, are entirely safe and hence, do not fall in the above criteria.

Furthermore, we performed one-way analysis of variance followed by a post hoc Tukey’s Honest significant difference test in graphing and analysis software Origin 9.1 (OriginLab Corporation, Northampton, USA). This test was performed to ascertain whether there was statistically significant difference between the mean of rotated screw with ideal screw fixation (i.e., no eccentricity). We chose the significance level (P value) of 0.05 or below.

**Results**

To ascertain a comparative risk study of blood vessels that are not visible during surgery, with different SCP, a relationship was established by measuring the distance between corresponding arteries, veins and all rotated screw according to their respective SCPs. In addition, it was apparently not possible to show all 18 possible ways of

| SCP   | Cup inclination angle (°) | Cup anteversion angle (°) | Screw angular eccentricity (°) | Eighteen developed angular eccentric SCP |
|-------|---------------------------|---------------------------|-------------------------------|----------------------------------------|
| SCP-1 | 45                        | 15                        | 0                             | SCP-1 (45-15-0)                        |
|       |                            | 20                        | 0                             | SCP-1 (45-20-0)                        |
| SCP-2 | 45                        | 15                        | 17                            | SCP-2 (45-15-17)                       |
|       |                            |                           | 34                            | SCP-2 (45-15-34)                       |
|       |                            | 20                        | 17                            | SCP-2 (45-20-17)                       |
|       |                            |                           | 34                            | SCP-2 (45-20-34)                       |
| SCP-3 | 45                        | 15                        | 17                            | SCP-3 (45-15-17)                       |
|       |                            |                           | 34                            | SCP-3 (45-15-34)                       |
|       |                            | 20                        | 17                            | SCP-3 (45-20-17)                       |
|       |                            |                           | 34                            | SCP-3 (45-20-34)                       |
| SCP-4 | 45                        | 15                        | 17                            | SCP-4 (45-15-17)                       |
|       |                            |                           | 34                            | SCP-4 (45-15-34)                       |
|       |                            | 20                        | 17                            | SCP-4 (45-20-17)                       |
|       |                            |                           | 34                            | SCP-4 (45-20-34)                       |
| SCP-5 | 45                        | 15                        | 17                            | SCP-5 (45-15-17)                       |
|       |                            |                           | 34                            | SCP-5 (45-15-34)                       |
|       |                            | 20                        | 17                            | SCP-5 (45-20-17)                       |
|       |                            |                           | 34                            | SCP-5 (45-20-34)                       |

SCP=Screw Configuration Profile

Figure 2: Schematic diagram showing illustration of the planes and axis of acetabular cup. Line originating from geometric center of acetabular cup, which is perpendicular to acetabular plane, is known as acetabular axis
the each angulated screws pictographically. Therefore, we analyzed and engraved all structures with their respective criteria (i.e., C1, C2, C3, and C4) in tabular format [Table 2].

**Statistical results**

For obturator artery, screws S0, S1, S4, S7, and S8 were found in its proximity. Screw S0 in SCP-4 (45-20-34) is statistically significant from ideal screw fixation (SCP-1) \( (P < 0.0001) \) therefore follows criteria C1. Screw S1 in SCP-3 (45-20-34) has the most significant difference \( (P < 0.0001) \) from SCP-1 (45-15-0) and therefore lies in criteria C4. We did not test the significance level in screw S4 because, in ideal SCP, the screw had a good bone stock. Exceptionally, screw S4 in SCP-5 (45-20-34) has the most significant distance of 7.60 mm and follows criteria C2. Screw S7 in SCP-2 (45-20-17) was not statistically different \( (P = 0.3493) \) from SCP-1 (45-20-0) and both lie in criteria C3. Screw S8 for all SCPs follows criteria C3.

External iliac vein lies in anterior quadrant encountered with screws S5, S6, S8, and S9 [Figure 4]. Screw S5 in SCP-5 (45-20-34) having most significant difference \( (P < 0.0001) \) among all eccentric profiles follows criteria C1. Screw S6 in SCP-3 (45-20-34) was significantly different \( (P < 0.0001) \) from ideal SCP and follows criteria C3 because of less bone stock. Screw S8 in SCP-3 (45-15-34) (45-20-17) (45-20-34) has most significant difference \( (P < 0.0001) \) with ideal SCP. Screw S8 in SCP-3 (45-15-34) (45-20-17) follows criteria C1 and in SCP-3 (45-20-34) follows criteria C3 due to insufficient bone stock. Screw S9 in SCP-2 (45-15-34) having most significant difference \( (P < 0.0001) \) with ideal SCP follows criteria C3 because of less bone stock.

The external iliac artery was adjacent to the anterior column and was found close to screws S5, S6, S8, and S9 [Figure 4]. Screw S5 in SCP-1 (45-15-0) was significantly different \( (P < 0.0001) \) from SCP-3 (45-15-17) and lies in...
Table 2: List of screws in all 18 eccentric screw configuration profiles following their respective criteria (i.e., C1, C2, C3, C4) relative to vessel structures proximal to pelvic bone

| SCP          | Obturator artery | External iliac vein | External iliac artery | Inferior gluteal artery | Superior gluteal artery |
|--------------|------------------|---------------------|------------------------|-------------------------|-------------------------|
|              | C1 | C2 | C3 | C4 | C1 | C2 | C3 | C4 | C1 | C2 | C3 | C4 | C1 | C2 | C3 | C4 |
| SCP-1 (45-15-0) | S4 | S7 | S8 | S0, S1 | S5, S6, S8, S9 | S5, S6, S8 | S0, S2, S12 | S3 | S12 |
| SCP-1 (45-20-0) | S4 | S7 | S8 | S0, S1 | S6, S8, S9 | S5 | S9, S5, S6, S8 | S0, S2, S12 | S3 | S12 |
| SCP-2 (45-15-17) | S4 | S7 | S8 | S0, S1 | S6, S8, S9 | S5 | S8, S6, S9 | S0, S2, S12 | S3 | S3, 12 |
| SCP-2 (45-15-34) | S0, S4 | S7 | S8 | S1 | S6 | S5, S9 | S9 | S8, S5, S6 | S0, S2, S12, S3 | S3 | S12 |
| SCP-2 (45-20-17) | S4 | S7, S8 | S0, S1 | S9 | S6 | S8 | S9 | S8, S5, S6, S9 | S0, S2, S12 | S3 | S12 |
| SCP-2 (45-20-34) | S4 | S7 | S8 | S0, S1 | S9 | S6 | S8 | S9 | S8, S5, S6, S9 | S0, S2, S12 | S3 | S12 |
| SCP-3 (45-15-17) | S4 | S7 | S8 | S0, S1 | S6, S8 | S5, S9 | S8 | S5, S6, S9 | S0, S2, S12 | S3 | S12 |
| SCP-3 (45-15-34) | S4 | S7 | S8 | S0, S1 | S8 | S6 | S5, S9 | S6, S8 | S5 | S9 | S2 | S0, S12 | S3 | S12 |
| SCP-3 (45-20-17) | S4 | S7 | S8 | S0, S1 | S8 | S6, S9 | S5 | S8 | S5, S6 | S9 | S3, S12 | S0, S2 | S3 | S12 |
| SCP-3 (45-20-34) | S4 | S7 | S0, S8 | S1 | S6, S8 | S5, S9 | S9 | S6 | S5, S6, S9 | S0, S2, S12 | S3 | S12 |
| SCP-4 (45-15-17) | S4 | S7 | S8 | S0, S1 | S6, S8 | S5, S9 | S9 | S6 | S5, S8 | S2, S3 | S12 | S0 | S3 | S12 |
| SCP-4 (45-15-34) | S0, S4 | S7 | S8 | S1 | S9 | S8 | S5 | S6 | S6 | S5, S8 | S2, S3 | S12 | S0 | S3 | S12 |
| SCP-4 (45-20-17) | S4 | S7 | S8 | S0, S1 | S9 | S6, S8, S5 | S6 | S6, S8, S9 | S5 | S2, S3 | S12 | S0 | S3 | S12 |
| SCP-4 (45-20-34) | S0, S4 | S7 | S8 | S1 | S9 | S8 | S5 | S6 | S6 | S8 | S0, S2, S3 | S3 | S12 |
| SCP-5 (45-15-17) | S4 | S7 | S8 | S0, S1 | S5, S6, S8, S9 | S5, S6, S8 | S0, S2, S3 | S3 | S12 |
| SCP-5 (45-15-34) | S7 | S8 | S0, S1, S4 | S5, S6, S8, S9 | S6, S8 | S9 | S5 | S6, S8 | S0, S2, S3 | S3 | S12 |
| SCP-5 (45-20-17) | S4 | S7 | S8 | S0, S1 | S6, S8 | S5 | S5, S6 | S5 | S0, S2, S3 | S3 | S12 |
| SCP-5 (45-20-34) | S4, S7 | S8 | S0, S1, S5 | S6, S8, S9 | S5, S6, S8 | S9 | S12 | S0, S2, S3 | S3 | S12 |

SCP=Screw Configuration Profile
criteria C1. Screw S6 in SCP-3 (45-15-34) is statistically different ($P < 0.0001$) with ideal SCP, and lies in criteria C1. Screw S8 in SCP-3 (45-20-17) was having a significant difference ($P < 0.0001$) with ideal SCP and follows criteria C1. Screw S9 in SCP-2 (45-15-34) is statistically different ($P < 0.0001$) and lies in criteria C1.

Inferior gluteal artery was found closer to the posterior column was encountered with S0, S2, S3, and S12 screws [Figure 4]. Screw S0 in SCP-5 (45-15-17) has the significant difference ($P < 0.0001$) but lies in C3 because of deficient bone stock. Screw S2 itself was most significant ($P < 0.0001$) from SCP-5 (45-15-17), followed criteria C3 because of less bone stock. Screw S3 in SCP-3 (45-20-17) was statistically different from ideal SCP ($P < 0.0001$) and lies in criteria C1. We did not perform any statistical analysis for screw S12 as the ideal screw lies inside the pelvic bone.

Superior gluteal arteries were close to the pelvic bone at the superior portion of the sciatic notch in the posterior quadrant and encountered with S3 and S12 screws [Figure 4]. Screw S3 in SCP-3 (45-20-17) was statistically different ($P < 0.0001$) from ideal SCP and lies in criteria C1. Statistical analysis was not performed for screw S12 because ideal SCP has the absolute bone stock.

**Discussion**

Researchers have published various reports on vascular injuries by placement of screws in context with THA; they are particularly dangerous since they can lead to the elimination or even to the death of the patient.6,12,20 In addition, external iliac vessel and obturator artery seem to have the most frequent injury because of their close proximity to the anterior column and quadrilateral surface, respectively.4,18 However, injury to internal iliac vessel, inferior, and superior gluteal vessel also has been reported.7,21,22

Wasielewski et al. described the quadrant system to prevent the vascular as well as neural structure, proximal to the pelvic bone. They recommended the use of quadrant system to place screws in cementless cup fixation, and hip arthroplasty surgeons already accepted it widely until date. In recent years, optimizing the total hip component, manufacturers are providing the eccentric hole (up to 34°) for screw fixation in acetabular cup. These eccentric cups may perhaps not abide the quadrant system provided by Wasielewski et al. However, we are aware of no similar reports (to our knowledge) on the effect of angular eccentric screws on vascular injury. Apart from this, Hsu et al. had studied the mechanical effect of press fit cup on the offset and angular eccentric screw in different experimental as well as the computational environment which is not directly associated with these findings.23,24 Thus, we sought to determine the effect of the eccentric screw for two angular rotations (17° and 34°), along with different configurations [Table 1].

The study used CT angiography scans, and special medical imaging and editing software Mimics18.0 to reconstruct the osseous and vessel structures of the pelvis. We also determined the distance between the intrapelvic blood vessels and impeding screw, following criteria C1, C2, C3, and C4 by Creo 3.0 parametric analysis tool.

From the results of the surgical simulation, measurements, and statistical analysis, it is evident that eccentric screws play a vital role in the vascular injury. Considering the quadrant system (proposed by Wasielewski et al.) and our findings, it is evident that the polar position is a rarely used position for a screw, because of deficient bone stock and presence of obturator artery. Thus, we can conclude that screws lying in the polar position were potentially dangerous for obturator artery. Visual determination provided that few screws, which lie in anterior or posterior quadrants in ideal fixation, were directed toward polar positions due to the angular rotation, and thus fell in the dangerous category for vessel structures.

Screws that lie in the posterior superior quadrant were not directed to the external iliac vessels or obturator artery. In addition, some of the SCP of the screws such as S10 of profile SCP-5 (45-15-17) (45-20-17), SCP-4 (45-15-34) (45-20-34), SCP-2 (45-15-17) (45-20-17) (45-15-34) (45-20-34), SCP-1 (45-15-0) (45-20-0) and S4 of profile SCP-4 (45-15-17) (45-20-17) (45-15-34) (45-20-34) and screw S11 of profile SCP-3 (45-15-34) (45-20-34) are not significant for use due to deficient bone stock. However, in ideal screw fixation, screws that lie in posterior superior quadrant or screws directed to the posterior superior quadrant as a result of eccentricity became safe.

Screws directed toward the posterior inferior quadrant lie close to the superior and inferior gluteal artery and pudendal artery, and yet are entirely safe in the vast majority of the angular eccentric profile [Table 1]. S11 might be downright insulted screw because of insufficient bone stock from transition zone of line-B [Figure 4] to the distal portion of the posterior quadrant.

The study addresses the critical issue of screws placed in an anterior quadrant in different eccentric SCP. Screws that lie in superior anterior quadrant or screws directed because of eccentricity occur in proximity to the external iliac artery and vein. Since the external iliac vein is more medial, or close proximal to the polar surface, the screws that lie in the anterior quadrant in ideal or eccentric fixation were possibly unsafe.

Angulated screws that lie in anterior inferior quadrant or screws that originate from other quadrant and are directed to anterior inferior quadrant are potentially dangerous for obturator artery, because the bone stock in this quadrant was significantly less in majority of the patients.

In general, a major finding of our study indicates that the quadrant system represented by Wasielewski et al. was
slightly different in relation to the modern prosthetic cup with the eccentric hole for screw fixation. Additionally, screws that were found probably dangerous for vessel structures in Wasiielewski findings could be significantly tolerable and benefited for due consideration as a result of angular eccentricity.

Perhaps, the most important result of the study predicts that the eccentric screw fixation is considered safe for criteria C1 and C2 and dangerous for C3 and C4 [Table 2]. As the direction of the eccentric screw tip and bone purchase can seriously affect the vascular structures proximal to pelvic bone, the surgeons are recommended to consider the criterion mentioned in our study [Table 2] together with the quadrant system proposed by Wasiielewski.

The study subjects to a few limitations. To start with, we performed the study only on an Indian populace, and the stature of the patients was fairly short. We did not examine the results with other populace, for example, in the Japanese, Chinese, Africans, USA, and Europe.

Second, we did not investigate patients with the hip disease such as osteoarthritis and rheumatoid arthritis, infection, revision surgery, gender, and protrusio. Therefore, our results may not apply to all patients with hip disease because the study was done in normal hip presumed to be undergoing primary THA; complex arthroplasty was not considered. We, however, believe that the present data maybe applicable to the patients requiring THA which are generally older and have atrophy of the muscles around the hip joint due to disuse.

Third, neural structures were not identifiable in angiographic CT. In most cases, these nerves keep company with the homonymous blood vessels in a neurovascular bundle. Along these lines, we tend to trust that a safe zone or dangerous zone for eccentric screws characterized by a vascular structure may be utilized likewise to avoid nerve injury.

Finally, we did not perform study on the aberrant anatomy of vessel structures and developmental dysplasia of hip. However, in our thirty eight patients’ data, no anatomical variants and dysplasia of hip were present.

Conclusion
Cementless cup with screw fixation in MI-THA is technically demanding. We trust that the data concerning the placement of eccentric screws in modern cup may be helpful in avoiding neurovascular injury. Further, the surgeons must consider the operating procedure to guarantee the safe screw placement with the angular eccentric hole in the prosthetic cup.

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Conflicts of interest
There are no conflicts of interest.

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