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Acetabular Anatomy and the Transacetabular Fixation of Screws in Total Hip Arthroplasty*

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ABSTRACT: **An anatomical and radiographic study was undertaken to determine the safest zones in the acetabulum for the transacetabular placement of screws during uncemented acetabular arthroplasty. To avoid injury to intrapelvic structures, which are not visible to the surgeon during placement of the screws, cadavera were studied to define the location of these structures with respect to fixed points of reference within the acetabulum.**

Four clinically useful acetabular quadrants were delineated. The quadrants are formed by drawing a line from the anterior superior iliac spine through the center of the acetabulum to the posterior fovea, forming acetabular halves. A second line is then drawn perpendicular to the first at the mid-point of the acetabulum, forming four quadrants.

The posterior superior and posterior inferior acetabular quadrants contain the best available bone stock and are relatively safe for the transacetabular placement of screws. The anterior superior and anterior inferior quadrants should be avoided whenever possible, because screws placed improperly in these quadrants may endanger the external iliac artery and vein, as well as the obturator nerve, artery, and vein.

The acetabular-quadrant system provides the surgeon with a simple intraoperative guide to the safe transacetabular placement of screws during primary and revision acetabular arthroplasty.

Total hip arthroplasty is one of the most commonly performed orthopaedic procedures. As the preliminary results of arthroplasty without cement and of hybrid total hip arthroplasty have become available, more surgeons have begun to use uncemented acetabular components, particularly in revision total hip arthroplasty. The fixation of uncemented components necessitates a departure from traditional techniques of acetabular arthroplasty with cement, since many of these porous-coated components use transfixation screws to stabilize the acetabular component until ingrowth of bone occurs.

The transacetabular fixation of screws necessitates drilling of the acetabular bone, followed by measurement of the depth of the bone and then, occasionally by tapping, insertion of the screws that anchor the prosthesis into the osseous columns and medial wall of the acetabulum. The screws should be placed in the areas of the acetabulum that provide the best bone stock for purchase while minimizing the risk of damage to vital intrapelvic structures. The anatomical structures that are contiguous to the acetabulum, which are not visible to the surgeon during acetabular arthroplasty, have been illustrated in many publications[4,6-8,11,12,15,18,19,27]. These structures are the external iliac, obturator, superior and inferior gluteal, and internal pudendal arteries and veins and the obturator, superior and inferior gluteal, internal pudendal, and sciatic nerves. To minimize risk during the placement of the screws, it is necessary to define the relationship of these neural and vascular structures to the osseous acetabulum, which the surgeon is able to see during total hip arthroplasty.

The purposes of this study were to define the anatomical structures that are at risk during the transacetabular placement of screws, to determine the relative contiguity of intrapelvic neural and vascular structures to screws placed in specific locations of the acetabulum, and to develop a quadrant system, with discernible operative landmarks, to guide in placement of the screws during primary and revision acetabular arthroplasty.

Materials and Methods

Seven pelves of the cadavera of mature adults, including the muscles, nerves, abdominal contents, and the vasculature from the umbilicus to the mid-part of the femur, were obtained. The transected abdominal aorta was ligated with a suture and then injected with 120 milliliters of radiopaque silicone injection compound.

Arterial filling was verified by observing the run-off from the distal part of the femur. The femoral arteries were then ligated bilaterally. The venous system was injected similarly, except in retrograde fashion to avoid valvular obstruction to filling. The sciatic nerve was located, just distal to the quadratus femoris muscle, and a flexible metal

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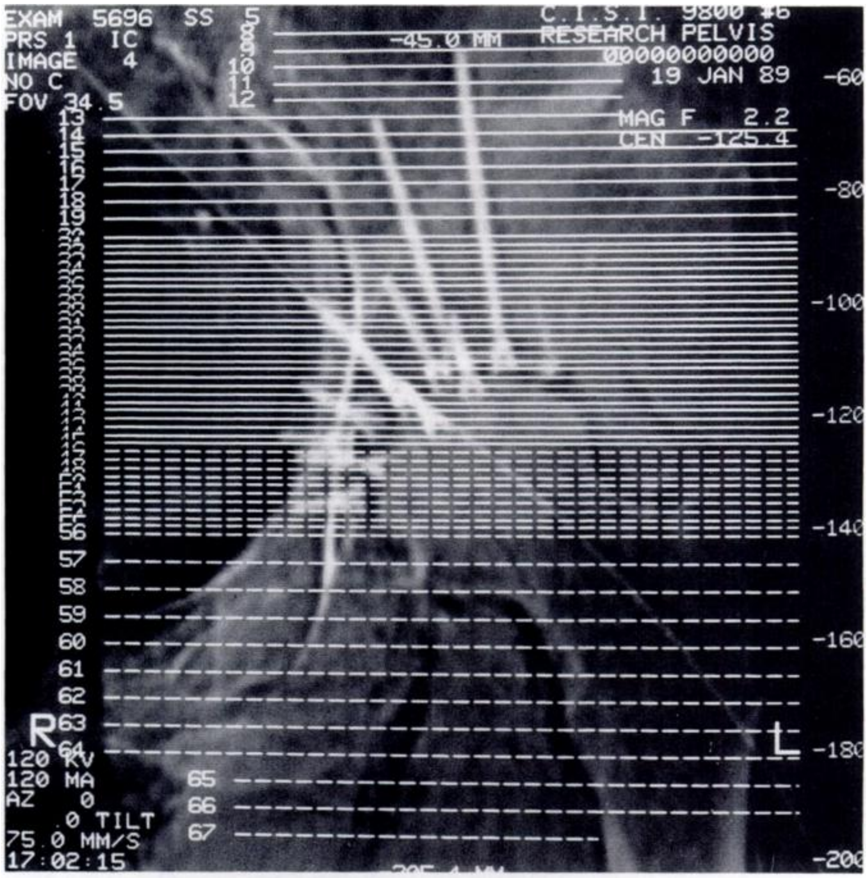

FIG. 1

Scout scan for computed tomography of a cadaver pelvis. The screws are perpendicular to the acetabular surface. The external iliac vein is opacified. A metal guide-wire is located in the sciatic nerve.

guide-wire was placed in the nerve.

The acetabular portion of a total hip arthroplasty was performed through an anterolateral incision. The acetabulum was reamed, and a properly sized acetabular component (HGP-I; Zimmer, Warsaw, Indiana, or Universal, Rutherford, New Jersey) was used as a template for transacetabular drilling. The cup was oriented in 45 degrees of abduction and 15 degrees of anteversion. The rotation of the component's shell in the acetabulum was random. With use of a guide, holes were drilled perpendicular to the cup and through the inner table of the acetabulum. The acetabular component was removed and the holes were measured with a depth-gauge. Care was taken to penetrate the medial bone minimally during drilling and measurement. Screws that were fifteen millimeters longer than the measured depth were placed through the acetabular bone and into the pelvis to allow visualization of the screws on radiographs and anatomical dissections.

Standard anteroposterior, lateral, and iliac and obturator oblique radiographs were made of each pelvis after injection of the latex and placement of the screws. Computed tomographic scans of each pelvis were made before dissection to ensure that accurate relationships were preserved between the screws and the undisturbed vasculature (Fig. 1). Three-dimensional reconstruction with the computed tomographic data was subsequently performed. Visualiza-

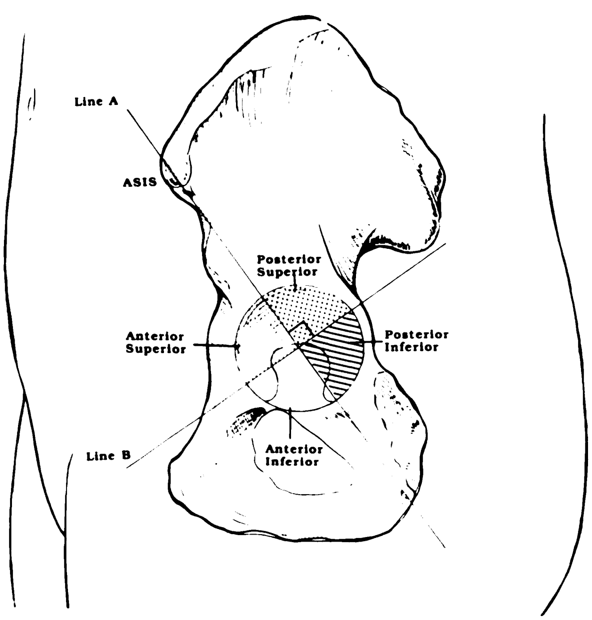

FIG. 2

The acetabular-quadrant system. The quadrants are formed by the intersection of Lines A and B. Line A extends from the anterior superior iliac spine (ASIS) through the center of the acetabulum to the posterior aspect of the fovea, dividing the acetabulum in half. Line B is drawn perpendicular to Line A at the mid-point of the acetabulum, dividing it into four quadrants: the anterior superior quadrant, the anterior inferior quadrant, the posterior superior quadrant, and the posterior inferior quadrant.

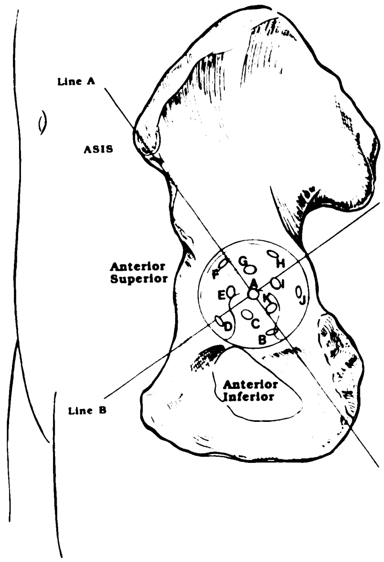

FIG. 3-A

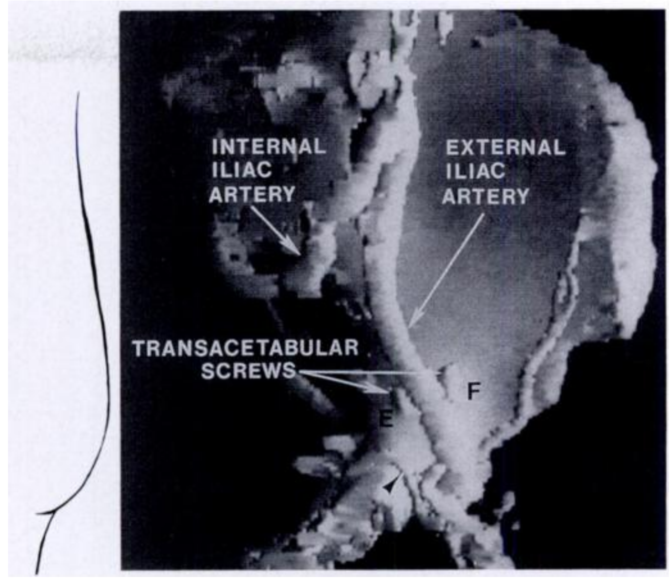

FIG. 3-B

Figs. 3-A, 3-B, and 3-C: Data obtained from the transacetabular placement of screws in a cadaver, with use of arterial opacification.
Fig. 3-A: Schematic drawing showing the acetabular origin of the screws (labeled A through K). ASIS = anterior superior iliac spine.
Fig. 3-B: Three-dimensional reconstruction of a computed tomographic scan, showing the position of the screws (E and F) and their relationship to the external iliac artery. The acetabular origin of these screws is the anterior superior quadrant (Fig. 3-A). The orientation is the same as in Fig. 3-C. Arrowhead = aberrant obturator artery.

tion of the vasculature, the flexible metal guide-wire in the sciatic nerve, and the transacetabular screws on the radiographs and scans made it possible to determine the anatomical course and proximity of the sciatic nerve and of the external iliac, obturator, superior and inferior gluteal, and internal pudendal vessels to specific screws placed through the acetabulum.

Precise anatomical dissections were then done. The pelves were eviscerated through a midline abdominal incision, with care not to disturb the parietal peritoneum covering the iliac vessels and inner pelvic wall. The peritoneum was carefully dissected from the external iliac vessels, obturator vessels, and obturator internus muscle lining the medial portion of the acetabulum. Screws that had penetrated the bone were then seen in relation to the nerves and vessels. These screws were traced back to the acetabular surface to determine their specific acetabular origin.

Two additional studies were conducted to determine the relative risk of different positions of the acetabular screws. The distance from the pelvic bone to the pertinent neural and vascular structures was measured on computed tomographic scans of the seven cadaver pelves and of twenty-five normal pelves of age-matched patients for whom computed tomographic scans had been made for unrelated reasons. The scans were examined at the level of the sciatic notch, the anterior inferior iliac spine, the acetabular dome, and the ischial spine. The distances from the external iliac artery and vein and the sciatic nerve to the bone were then measured at each level. Similar data were obtained for the obturator, inferior and superior gluteal, and internal pudendal vessels, which were visible on the enhanced computed-tomographic scans. This information was used to define the relative susceptibility of nerves and vessels to over-penetration during drilling, tapping, and bone-depth measurement, and it allowed a quantitative assessment of the margin for error.

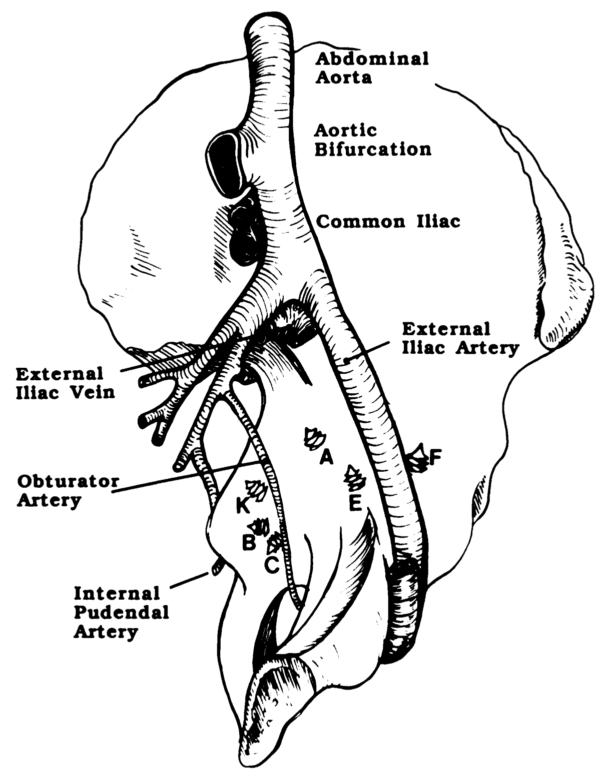

FIG. 3-C

Schematic diagram showing the location of excessively long screws on the quadrilateral intrapelvic surface relative to the iliac arterial system. Screws E and F are near the external iliac artery; their acetabular origin is the anterior superior quadrant (Fig. 3-A).

Bone depth was measured for each screw that was placed into the seven cadaver pelves that had been injected

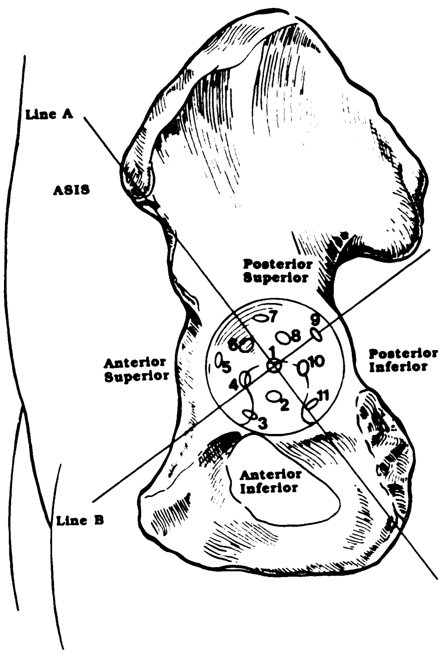

FIG. 4-A

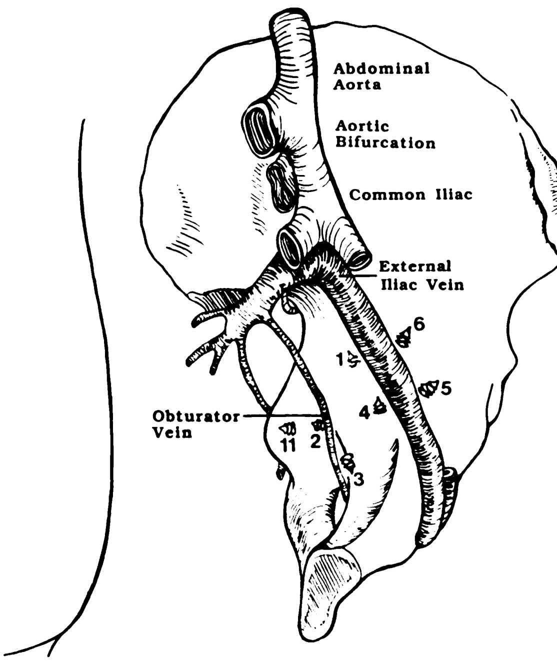

FIG. 4-B

Figs. 4-A through 4-D: Data obtained from the transacetabular placement of screws in a cadaver, with use of venous opacification.

Fig. 4-A: Schematic diagram showing the acetabular origin of the screws (numbered 1 through 11). ASIS = anterior superior iliac spine.

Fig. 4-B: Schematic diagram showing the location of the screws on the quadrilateral intrapelvic surface relative to the iliac venous system. Screws 1, 4, 5, and 6 are near the external iliac vein; their acetabular origin is the anterior superior quadrant (Fig. 4-A). Screws 2 and 3 are near the obturator vein; their acetabular origin is the anterior inferior quadrant (Fig. 4-A).

with latex. In two additional hemipelves, multiple holes, spaced five millimeters apart, were drilled perpendicular to the acetabular bone. Bone depths were then measured with a standard depth-gauge and were plotted so that a topographic map of the acetabular bone depth could be formulated.

A structure was considered to be at risk if it was accessible to screws placed perpendicular to the acetabulum; contiguous to the surface of the intrapelvic bone, with little interposition of tissue or acetabular bone; relatively adherent to the pelvis; and difficult to see or palpate during acetabular arthroplasty. An acetabular-quadrant system was constructed to define the acetabular screw positions that pose the greatest risk of damage to intrapelvic neural and vascular structures.

Results

The acetabular quadrants are formed by extending a line from the anterior superior iliac spine through the center of the acetabulum, resulting in anterior and posterior halves (Fig. 2, Line A). A second line drawn perpendicular to Line A at the center of the acetabulum forms superior and inferior acetabular halves (Fig. 2, Line B). The four quadrants formed by the intersection of Lines A and B are the anterior superior quadrant, the anterior inferior quadrant, the posterior superior quadrant, and the posterior inferior quadrant. A constant relationship was found to exist between specific acetabular quadrants and specific intrapelvic structures.

Arterial and venous studies showed that screws placed in the anterior quadrants were directed toward the external iliac and obturator vessels and the obturator nerve (Figs. 3-A through 4-E). No screw passed near the sciatic, superior and inferior gluteal, or internal pudendal nerves or near the superior and inferior gluteal and internal pudendal vessels. The results were the same in each cadaver pelvis that was tested.

Screws originating from the anterior superior quadrant were found to lie near the external iliac artery (Figs. 3-A, 3-B, and 3-C) and vein (Figs. 4-A, 4-B, and 4-C). However, because of the more medial position of the vein with respect to the artery and the paucity of interposed tissue along the pelvic brim, the external iliac vein was more in danger of injury than was the artery (Figs. 4-D and 4-E).

Screws originating from the anterior inferior quadrant were directed toward the obturator nerve and vascular structures (Figs. 3-A, 3-C, 4-A, 4-B, and 4-E). This was most evident at the superolateral aspect of the obturator foramen, where the nerve, artery, and vein exit the true pelvis through the obturator canal. When an anatomical variant was present (the aberrant obturator artery in Figure 3-B and the accessory obturator vein in Figures 4-C, 4-D, and 4-E), these vessels were even more susceptible to injury. The accessory or aberrant obturator vessels travel across a section of the pelvic brim (located just opposite the anterior inferior quadrant) with little interposed soft tissue. This section of the osseous acetabulum is thin (six to twelve millimeters), which increases the possibility of vascular injury.

Screws placed in the center of the acetabulum at the intersection of Lines A and B (polar position) exited the pelvis through the quadrilateral surface and were near the

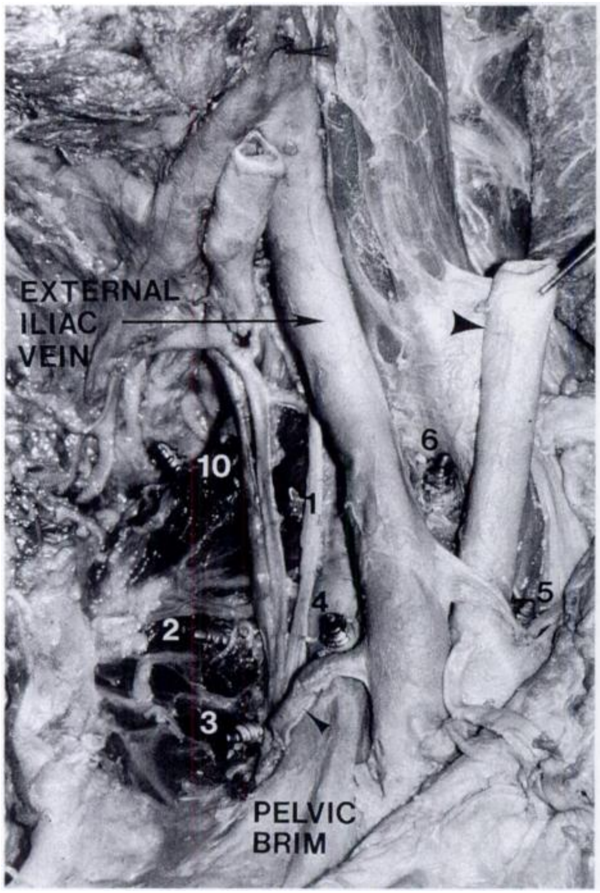

FIG. 4-C

Photograph of a dissection. Screws 1, 4, 5, and 6 are near the external iliac vein. An accessory obturator vein (small arrowhead) is shown traveling across the pelvic brim from the obturator foramen to the external iliac vein. The orientation is the same as in Figure 4-B. Large arrowhead = external iliac artery.

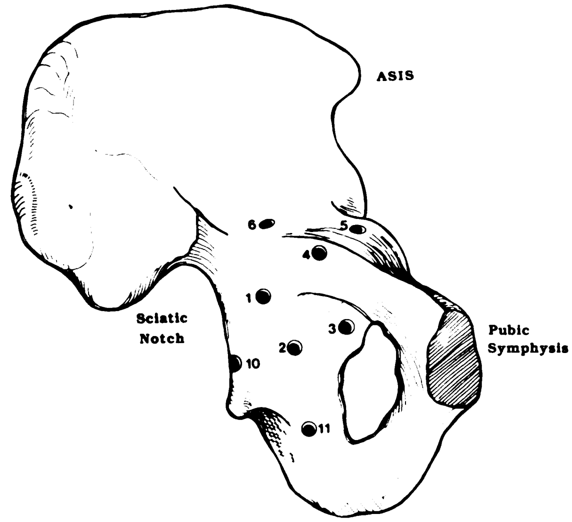

FIG. 4-D

Schematic diagram showing the quadrilateral intrapelvic surface and the location of the screws. The holes are numbered according to their acetabular origin (Fig. 4-A). ASIS = anterior superior iliac spine.

obturator nerve, artery, and vein (Figs. 3-A through 4-E). The obturator internus muscle provided minimum interposition of tissue along the quadrilateral surface and was often sparse and insufficient. This situation was worsened by the thin plate of bone opposite the polar position of the acetabulum. Screws as short as fifteen millimeters that were located around the polar position of the acetabulum were found to endanger the obturator nerve and vessels.

Screws placed in the posterior quadrants can be directed toward the sciatic nerve and inferior gluteal vessel but are directed away from the external iliac vessels and obturator vessels and nerve. Screws longer than twenty millimeters that are inserted along the rim of the posterior column are near the sciatic nerve along its extrapelvic portion. These screws are palpated by placing the finger around the brim of the acetabulum during insertion; screws of the proper size can easily be placed while the sciatic nerve is avoided. Screws that are located centrally in the posterior superior quadrant (Fig. 4-A) may be directed toward the superior gluteal nerve, artery, and vein as they exit the pelvis through the greater sciatic notch. However, in our study, the bone

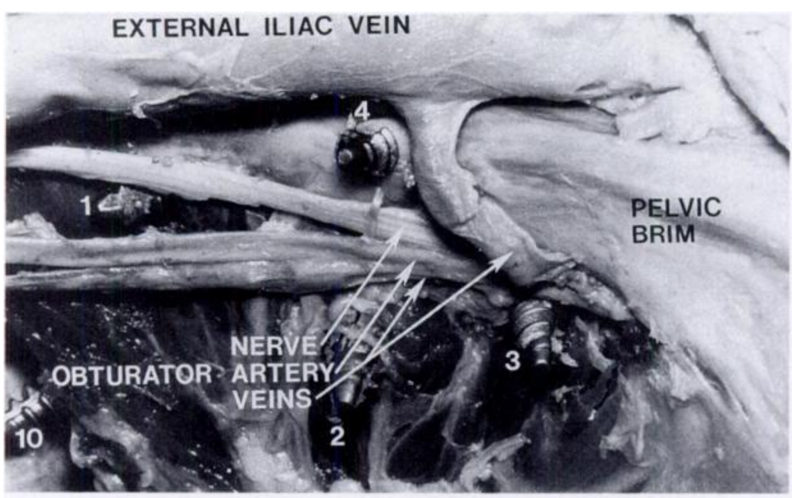

FIG. 4-E

Photograph of a dissection. Screw 1 (Fig. 4-A, polar position) and screws 2 and 3 (Fig. 4-A, anterior inferior quadrant) are close to the obturator nerve, artery, and vein. The external iliac vein and accessory obturator vein lie against the bone at this level, with little interposition of tissue. The orientation is the same as in Fig. 4-D.

depth in the central zone of the posterior superior quadrant was always more than twenty-five millimeters. Screws that are located centrally in the posterior inferior quadrant (Figs. 4-A and 4-D) are directed toward the inferior gluteal and internal pudendal nerves and vessels. These structures are rarely endangered, due to surrounding intrapelvic tissue and their distance from the posterior column. The deeper bone depths in the central zones of the posterior inferior quadrant also afford decreased risk of damage to vessels or nerves caused by screws (Fig. 5).

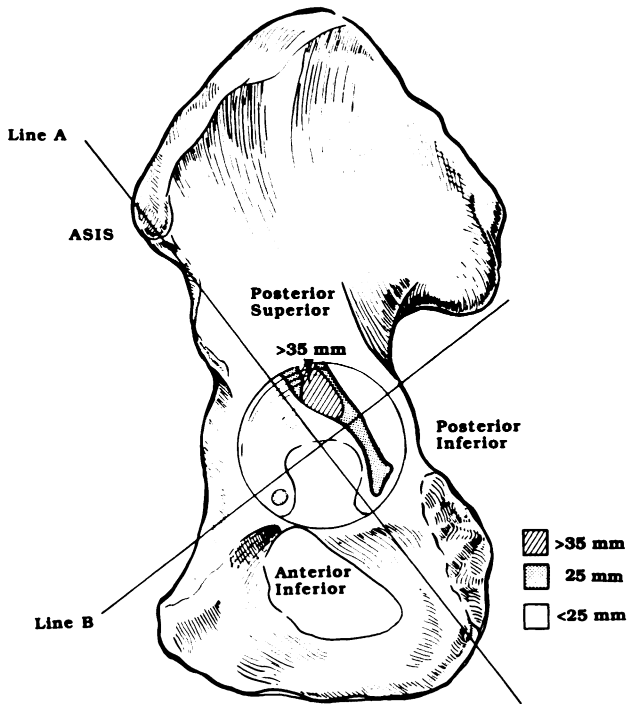

FIG. 5

Topographic map of acetabular bone depth, showing a large central zone in the posterior quadrants in which screws twenty-five millimeters in length can be placed entirely within bone. The posterior superior quadrant also contains a zone in which screws longer than thirty-five millimeters can be placed in the ilium. ASIS = anterior superior iliac spine.

Screws placed along Line A in the transition zone dividing the acetabular quadrants behave similarly to those in the anterior quadrants. Screws inserted along Line A in the superior portion of the acetabulum (separating the anterior superior from the posterior superior quadrant) most often lie within the psoas muscle. These screws, although protected by interposition of the psoas muscle, are directed toward the external iliac artery. Screws inserted along Line A in the inferior portion of the acetabulum (separating the anterior inferior from the posterior inferior quadrant) lie close to the obturator neural and vascular structures.

A review of the data on acetabular bone depths revealed that the greatest depths for purchase of the screws are located in the more central zones in the posterior quadrants (Fig. 5). In our specimens, bone depths in this region were at least twenty-five millimeters. In the posterior superior quadrant, screws as long as eighty-five millimeters were placed between the inner and outer tables of the ilium in the direction of the sacro-iliac joint. In comparison, the bone stock of the anterior quadrant is relatively shallow. Except for a small zone directed toward the superior pubic ramus, only screws less than twenty-five millimeters could be used in the anterior quadrants (Fig. 5).

A review of the computed tomographic scans of the twenty-five patients who had a normal pelvis demonstrated that the sciatic nerve was closest to the posterior column from the level of the anterior inferior iliac spine to the acetabular dome. When the nerve was intrapelvic it was farther from the bone. This was also the case distal to the ischial spine. At its point of exit from the pelvis, the sciatic nerve was an average distance of thirteen millimeters (range, nine to twenty-one millimeters) from the bone. At the level of the acetabular dome, the distance from the posterior column averaged only nine millimeters (range, six to eleven millimeters). At the ischial spine, this distance increased to fifteen millimeters (range, thirteen to twenty-two millimeters) due to the interposition of the gemelli, obturator internus, and quadratus femoris muscles.

The superior gluteal vessels were closest to the pelvic bone at the superior portion of the sciatic notch. Computed tomographic scans of the seven cadaver pelves (opacified vascular) at this level showed that the superior gluteal vessels were an average distance of five millimeters (range, two to ten millimeters) from the greater sciatic notch. These structures are not palpable at the sciatic notch. However, because the bone depths of the posterior superior quadrant were at least twenty-five millimeters, no screw of that length or less was a potential threat to these structures.

The inferior gluteal and internal pudendal vessels were closest to the posterior column at the level of the ischial spine. Computed tomographic scans showed that the average distance was six millimeters (range, five to eight millimeters) for the internal pudendal artery and twelve millimeters (range, ten to fourteen millimeters) for the inferior gluteal vessels. Dissections showed that these structures are protected by surrounding perineural fat and are very mobile.

The external iliac artery and vein and the obturator structures are close to the anterior column and are relatively non-mobile. They are held tightly to the pelvis by the parietal peritoneum and are most vulnerable to injury along the arcuate line. Proximal to the arcuate line, these structures are at less risk of injury because they are farther from the bone. Measurements from the twenty-five normal pelves at the level of the anterior inferior iliac spine demonstrated that the external iliac vein was closer to the anterior column than was the external iliac artery (seven and ten millimeters, respectively; ranges, five to eleven millimeters and eight to sixteen millimeters). This was because different amounts of psoas muscle are interposed between the bone and these structures. At the acetabular dome, a similar relationship was present, but both vessels were considerably closer to the bone of the anterior column: the vein, four millimeters (range, two to seven millimeters) and the artery, seven millimeters (range, five to ten millimeters). The obturator structures lay against the bone along the quadrilateral surface with as little as one millimeter of interposition of the obturator internus muscle.

Discussion

Vascular injuries are an uncommon yet potentially devastating complication of total hip arthroplasty. Direct trauma to intrapelvic neural and vascular structures has been related to placement of instruments[13,16,23], removal of extruded cement during revision[3,16,17,20,21], and migration of the prosthesis[2,5,10,22,24]. Damage to the external iliac artery seems to have been the most frequent injury[1,2,9,16,20,24-26]. Injury to the external iliac vein[14] and the superior gluteal artery[13] also have been reported.

The quadrant system that we have developed for locating the position of neural and vascular structures that are at risk during primary acetabular arthroplasty is easy to construct. For simplicity, during a revision procedure, when the original osseous acetabulum is partially intact and the fovea may be absent, a line drawn from the anterior superior iliac spine that divides the acetabulum into equal halves can be used to form the quadrants. If this line is then bisected with a perpendicular at its mid-point, four quadrants are formed. The quadrants can be used to locate safe and dangerous zones for the transacetabular placement of screws.

The use of the anterior quadrants for the placement of screws may endanger the external iliac artery and vein and the obturator nerve, artery, and vein, because the screws are directed toward these structures, which lie close to the pelvic bone, with little protective interposition of soft tissue. The lack of bone in the anterior quadrants exacerbates the risk. Placement of screws in these quadrants should therefore be avoided whenever possible.

The polar position of the acetabulum represents a commonly used position for a screw. However, the use of this position frequently results in the placement of a screw near the obturator nerve and vessels along the superior quadrilateral surface. The risk to these structures is increased by the lack of interposition of the obturator internus muscle and the shallow acetabular bone depth opposite the structures.

Screws that are placed in the posterior quadrants, perpendicular to the acetabular surface, are not directed toward the external iliac or obturator structures. If placed in the posterior superior quadrant, the screws may be directed toward the sciatic nerve and the superior gluteal nerve and vessels. In contrast to the shallow bone in the anterior quadrants, the bone depth in the posterior superior quadrant allows screws twenty-five millimeters or longer to be placed safely in the posterior acetabular column and acetabular dome. The mobility of the sciatic nerve also allows it to be displaced by the surgeon during placement of the screws, further decreasing the susceptibility of the nerve to injury. The superior gluteal nerve and vessels are not palpable, but they can be protected if screws no longer than twenty-five millimeters are used in the central regions of the posterior superior quadrant.

Screws that are placed in the posterior inferior quadrant lie near the inferior gluteal and internal pudendal neural and vascular structures. These structures are not palpable at the level of the ischial spine, but they can be protected if screws twenty-five millimeters or shorter are used. Longer screws would exit the posterior column, risking injury.

Even though screws in the posterior quadrant are directed toward important neural and vascular structures, the risk to these structures is minimized by palpation of the sciatic nerve, a bone depth of at least twenty-five millimeters between the acetabular surface and the superior gluteal and internal pudendal nerves and vessels, and the inherent mobility of the sciatic nerve and of the internal pudendal and inferior gluteal structures. Placement of the screws in the posterior quadrants decreases the risk to neural and vascular structures during acetabular arthroplasty.

Screws that are located along Line A, in the transitional zone between the anterior and posterior quadrants, often endanger neural and vascular structures. Recently designed acetabular components that provide varying amounts of freedom to angle the screws from the perpendicular may allow safe use of these ambiguous positions. The screws can be directed posteriorly, toward the safe posterior quadrants. Thus, an operatively accessible transitional hole that would otherwise be considered dangerous may be used safely.

Operative technique is the most important factor in ensuring the safe transacetabular placement of screws. Even when the safe zones for the placement of the screws are known, the structures can be damaged by inadvertent violation of the intrapelvic region. During normal insertion of the screws, injury is most frequently caused by the drill during plunging. However, penetration of the pelvis by the tap or depth-gauge can also cause harm.

The acetabular-quadrant system also can be helpful during revision acetabular arthroplasty. Provided the anterior superior iliac spine can be palpated, the line dividing the acetabulum into anterior and posterior halves can be constructed. Screws can be directed away from neural and vascular structures and toward acetabular zones that are likely to contain the best available bone stock. Even in the most deformed acetabulum, a general knowledge of the location of the pertinent neural and vascular structures, while not absolute, can be very useful.

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