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ORIGINAL ARTICLE • PELVIS - FRACTURES

Gun barrel view of the anterior pelvic ring for percutaneous anterior column or superior pubic ramus screw placement

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Abstract
Background Traditionally, operative fixation of pelvic and acetabular injuries involves complex approaches and significant complications. Accelerated rehabilitation, decreased soft tissue stripping and decreased wound complications are several benefits driving a recent interest in percutaneous fixation. We describe a new fluoroscopic view to guide the placement of screws within the anterior pelvic ring.
Methods Twenty retrograde anterior pelvic ring screws were percutaneously placed in ten cadaveric specimens. Arranging a standard C-arm in a position similar to obtaining a lateral hip image, with angles of 54° ± 2° beam to body, 75° ± 5° of reverse cantilever and 14° ± 6° of outlet, a gun barrel view of the anterior pelvic ring is identified. Fluoroscopic images were taken, and the hemipelvi were harvested to examine the dimensions of the anterior pelvic ring and inspected for any cortical or articular perforation.
Results The minimum cranial-to-caudal distance in the anterior pelvic ring was 9 mm (range 6.5–12 mm), and the minimum anterior-to-posterior dimension was 9 mm (range 5–15 mm). All but 2 screws were completely confined within the osseous corridors. Identifiable on final fluoroscopic evaluation, one screw perforated the psoas groove and a second perforated the acetabular dome. Overall, 90 % of our screws were accurately and safely placed, upon the first attempt, within the anterior pelvic ring using the described gun barrel view.
Conclusion Employing either open reduction, or following a closed or percutaneous reduction, the anterior pelvic ring gun barrel view can reproducibly guide safe placement of anterior pelvic ring screw fixation.
Level of evidence IV.

Keywords Percutaneous screw fixation · Anterior column · Acetabular fracture · Superior pubic ramus · Gun barrel

Introduction

Six decades ago, Dr. Emile Letournel published his results and findings regarding acetabular approaches and results from surgical treatment. Such research established the foundation for our understanding of pelvic and acetabular fractures and greatly contributed to modern treatment. Operative fixation through open approaches was advocated to minimize mechanical aggravation of the vascular damage incurred from injury and to decrease the chance of post-traumatic arthritis. Not indicated for operative fixation, non-displaced fractures were treated with bed rest, passive range of motion and massage for the first 45 days. In the following 45 days, therapy was advanced to non-weight bearing and crutch walking and progressive weight bearing thereafter [1].

Since then, decades of experience and evolving technology have further advanced the treatment of pelvic and acetabular fractures. Motivated to decrease bed rest, accelerate mobilization and weight bearing, especially in the elderly and multiply injured, research for percutaneous reduction and fixation of pelvic and acetabular fractures has emerged. Through an increasing understanding of the

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anatomy, radiographic landmarks and mechanisms of injury, indications for percutaneous fixation are being defined. Reported indications include fractures in patients with multiple medical comorbidities, those who cannot comply with nonoperative protocols, associated-severe soft tissue degloving, open injuries, polytrauma, renal transplants, non-displaced or minimally displaced fractures and fractures in the elderly [2–12]. Pelvic and acetabular fractures in the elderly are also considered for percutaneous fixation, as it has been shown that open reduction and internal fixation of acetabular fractures with poor bone quality are a more technically demanding procedure and these patients have poorer outcomes [6, 10]. As the indications for percutaneous pelvic ring or acetabular fixation become more definite, the techniques for placement of such screws are a source of ongoing research.

The purpose of this investigation was to identify and describe the imaging technique required to obtain a gun barrel view of the anterior pelvic ring (APR), identify its radiologic lines and report our results in placing percutaneous retrograde anterior pelvic ring screws using only this one view. A secondary purpose was to describe the anatomy of the osseous corridor and relate such anatomy to placing screws in this region. The Biosciences Center at Miami Valley Hospital approved our protocol and the use of the donated cadavers.

Materials and methods

This study was approved by the Clinical Research Center at Miami Valley Hospital. Thirteen (13) human cadavers were obtained through the Anatomical Gift Program at the Boonshoft School of Medicine at Wright State University and used at the Biosciences Center at Miami Valley Hospital.

The first 3 cadavers were preliminarily used to help develop our protocol regarding which measurements were to be made and how to obtain and report such measurements. In addition, dissections were performed on these first 3 cadavers, during which anatomic landmarks were correlated with fluoroscopic radiographic lines. Figure 1 demonstrates an APC gun barrel view and its appropriately identified landmarks.

Information regarding the donors was limited, but they did vary in height and size to include cachectic and obese specimens. Of the 10 included in the study, 7 were male and 3 were female. All specimens were placed in supine position, arms crossed over their chest, and hip bumps were placed as necessary to obtain a level pelvis to the eyes of the examiners. Cadavers were placed on spine boards supine and set atop steel tables at either ends of the spine board (Fig. 2a, b). The C-arm was placed opposite the hemipelvis of concern and orthogonal to the patient. The monitor was placed at the foot of the table. The base of the C-arm was then rotated caudally, toward the feet to achieve an angle of 55° with respect to the longitudinal axis of the patient's body, henceforth referred to as C-arm angle. A string connected from the image intensifier to the X-ray tube and a second string placed from the suprasternal notch to the center of the mons pubis, passing through the umbilicus, were used for this measurement. A goniometer was used to measure the angle at the intersection of the 2 strings. An antero-posterior image was taken, and the level of the base adjusted until the superior pubic ramus was in the center of the image. Measurement

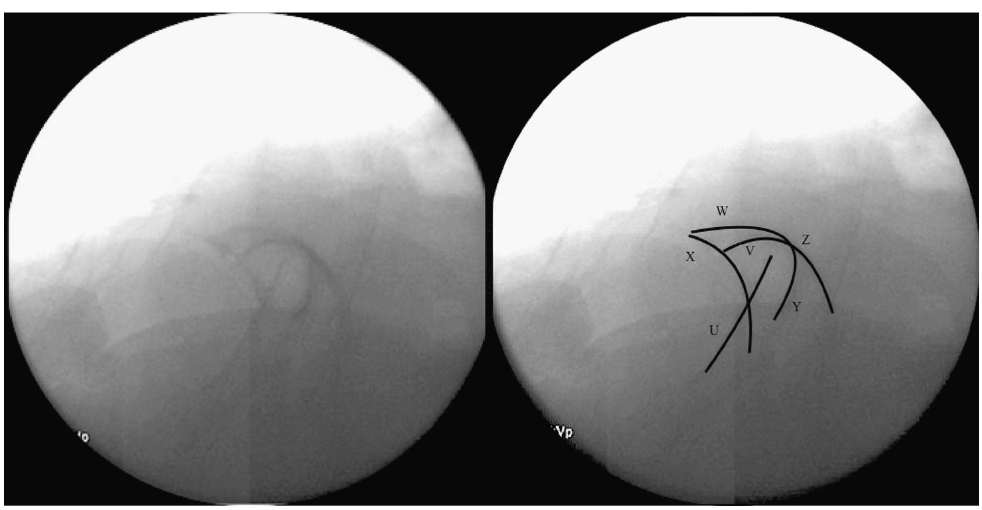

Fig. 1 Anatomic landmarks of anterior pelvic ring gun barrel view. *Left* Anterior pelvic ring gun barrel view. *Right* *U* anterior border of pubis, *V* anterior border of pubic ramus, *W* anterior acetabular wall, *X* acetabular dome, *Y* posterior limit of superior pubic ramus, *Z* cranial limit of superior pubic ramus

Fig. 2 Cadaver setup

of the base of the C-arm to the longitudinal axis of the body was checked again to ensure it was 55°. The C-arm was then reverse cantilevered (i.e., horizontal travel, backwards rainbow) to 75° and the outlet adjusted (caudal tilt) to 15°. An image was taken, the C-arm height adjusted accordingly, the image rotated on the screen to represent the actual orientation on the table, and the base was adjusted in a cranial–caudal direction until the desired radiographic landmarks were in the center of the picture. The image at this point typically appears as it does in Fig. 3a. Minor adjustments of C-arm base angle, cantilever and outlet are made to achieve the gun barrel view of the anterior pelvic ring (Fig. 3b). At this point, the 3 C-arm measurements (C-arm base angle, cantilever and outlet) were recorded (Table 1).

Attention was then aimed at placement of a cannulated 6.5 mm screw (Synthes, Paoli, PA, USA). A 6.5-mm screw was chosen based on the findings of various anatomic studies [8, 9, 13]. In developing our protocol, we began placing the guide wires via stab incisions. Upon dissecting the mons pubis, we found some of the guide wires had damaged the spermatic cord or round ligament. Thus, with our 10 specimens, a limited Pfannenstiel incision was employed to protect the urogenital structures. To achieve the desired starting point, the tip of the threaded guide wire is placed at the desired point within the gun barrel (Fig. 4a), typically gaining purchase of the bone just inferior to the pubic tubercle and lateral to the symphysis. We found advancing the guide wire was more controlled using a mallet to tap the wire and a needle driver or Kocher clamp to stabilize the wire. This also allowed us to more accurately assess our wire position without having to repeatedly remove a wire driver when space between the guide wire and image intensifier was limited. Occasionally the guide wire will skive off the pubis, whereupon the wire driver is used to start the guide wire orthogonal to the bone, then, gradually angle the wire to the desired trajectory. Once the desired starting point and trajectory were achieved (Fig. 4a), the wire was then fully seated (Fig. 4b) using a mallet, and the gun barrel view maintained without having to alternate between obturator oblique, iliac oblique, pelvic inlet and outlet views and combinations thereof. Once the guide wire was fully seated, we found the obturator outlet and inlet views to be the most useful for confirming wire position (Fig. 4c, d), similar to other authors [11]. A cannulated drill was used only to enter the first cortex and the partially threaded 6.5-mm cannulated screw was then inserted over the guide wire. The guide wire was removed, and final gun barrel, obturator outlet and inlet views were taken. The screw was removed, and the above was repeated on the contralateral side, step by step.

Following retrograde screw placement of both anterior pelvic rings, bilateral ilioinguinal approaches were performed and the innominate bones dissected and harvested. Once harvested, the bones were labeled by cadaver number and side (ex. 4L, 4R for specimen #1 right and left sides, respectively) and stored in a freezer. At the end of our experiment, the harvested hemipelvi were sectioned along a sagittal plane at various points (Fig. 5). A band saw was used to section the hemipelvi at the retrograde entry point, and at the narrowest anterior–posterior segment and the

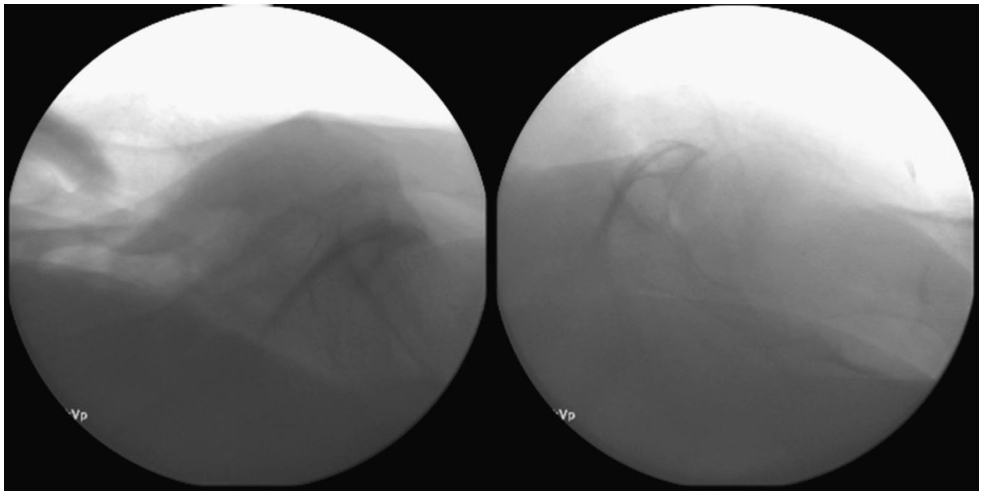

Fig. 3 Obtaining anterior pelvic ring gun barrel view. *Left* Pre-adjustments. *Right* Post-adjustments

Table 1 C-arm projections

Study specimen	Cadaver #	Beam-to-patient angle (°)	Cantilever (°)	Outlet (°)
1	4L	56	90	10
	4R	55	83	14
2	5L	55	76	30
	5R	55	76	25
3	6L	55	73	15
	6R	55	77	10
4	7L	55	75	13
	7R	55	73	14
5	8L	55	72	13
	8R	55	72	13
6	9L	50	74	6
	9R	53	75	7
7	10L	50	78	22
	10R	55	77	20
8	11L	55	74	17
	11R	55	74	16
9	12L	53	68	6
	12R	55	66	8
10	13L	55	70	15
	13R	50	69	15
Averages		54	75	14
SD		1.9	5.3	6.2

Beam-to-body angle describes the coronal plane angle between the C-arm and the patient's midline. Cantilever describes motion about the x axis, or roll. Outlet describes motion about the z axis, or tilt

narrowest cranial–caudal segment. These dimensions were then measured using calipers and recorded (Table 2). Of note, 2 hemipelvi had retained acetabular cups and polyethylene liners, which did not affect the sectioning or measurements.

Results

C-arm positioning (Table 1)

Averaging our data reveals a C-arm base angle of 54° ± 2°, 75° ± 5° of reverse cantilever and 14° ± 6° of outlet provide the described anterior pelvic ring bun barrel view; however, with varying anatomy, minor adjustments may be required.

Anatomic description (Table 2)

The average minimum cranial-to-caudal distance encountered in the anterior pelvic ring was adjacent to the acetabular dome and was 9 mm (range 6.5–12 mm). The average minimum anterior-to-posterior dimension was in the superior pubic ramus just medial to the iliopectineal eminence and was also 9 mm (range 5–15 mm). Our second specimen was prematurely taken to the crematorium prior to harvesting, and the hemipelvi lost for anatomic description. However, we did have the fluoroscopic images showing the screw placement, and it was felt there was no cortical or acetabular penetration (Fig. 6). As such, this specimen was included in our report of screw placement but not for the anatomic description.

Screw placement

All but 2 screws were completely confined within the osseous corridors of the anterior pelvic rings. One screw perforated the psoas groove; although once the screw was fully placed, the shaft of the screw was relatively confluent with the cortex it perforated and was recognized upon fluoroscopic imaging. The AP and obturator outlet views show acceptable guide wire positioning (Fig. 7a, b), yet the gun barrel view with the screw removed demonstrates

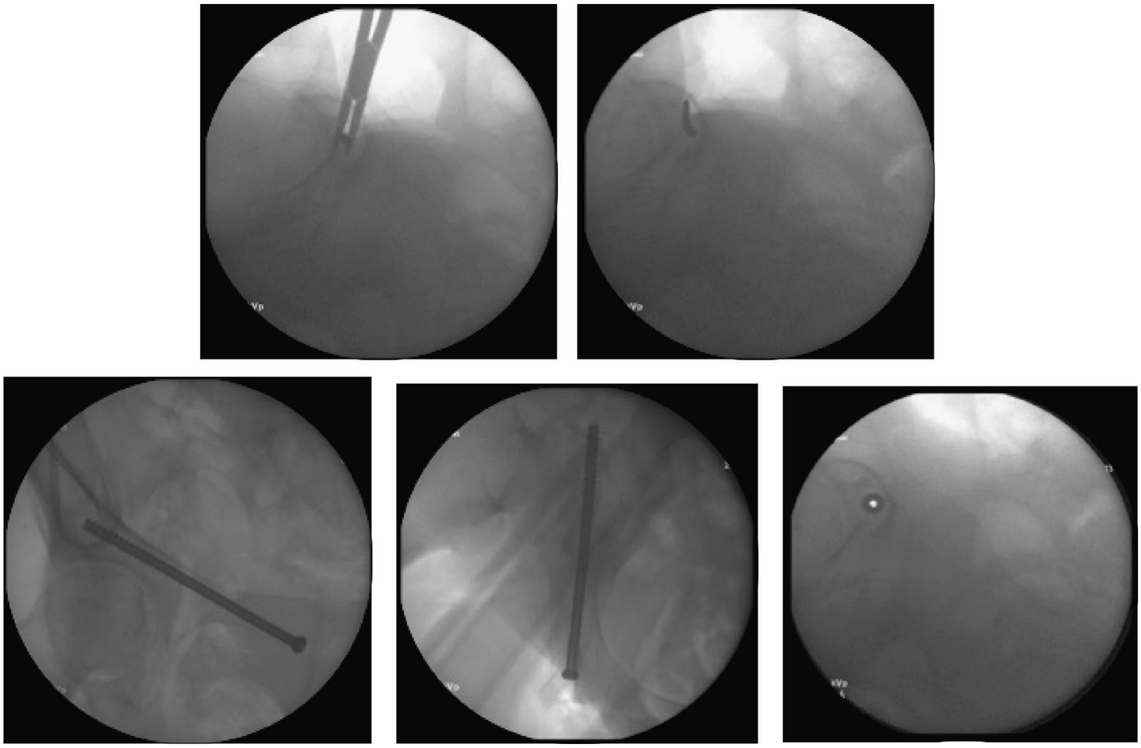

Fig. 4 Progression of placing an anterior pelvic ring screw. *Top left* Starting point. *Top right* Fully seated TGW. *Bottom left* Obturator outlet confirmation. *Bottom middle* Inlet confirmation. *Bottom right* Anterior pelvic ring gun barrel view

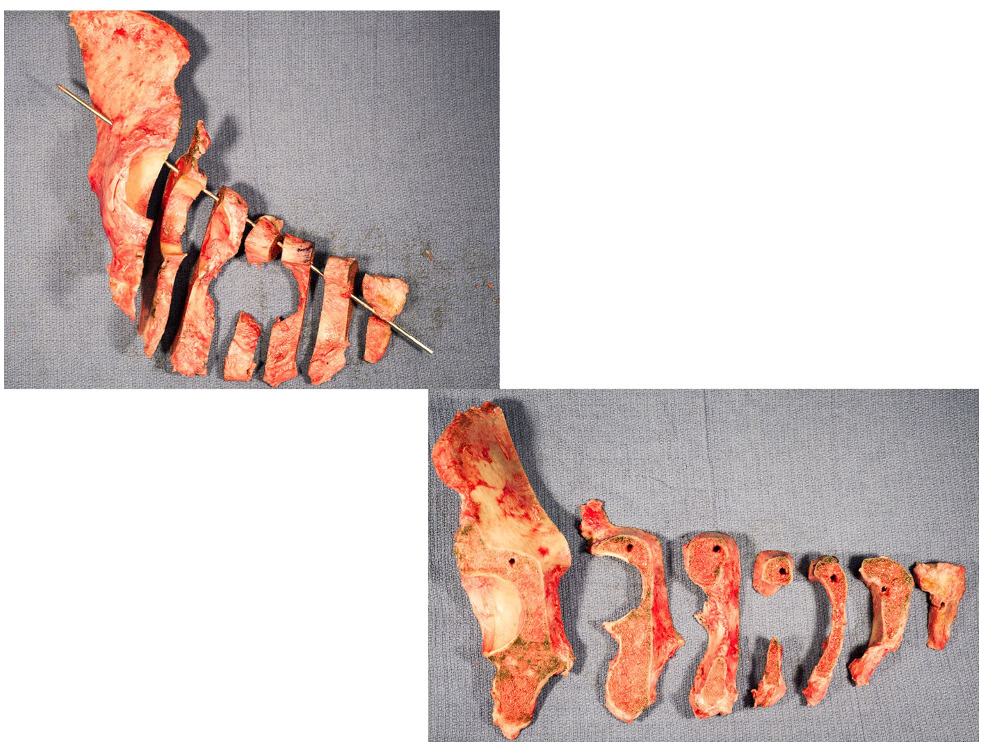

Fig. 5 Sectioned hemipelvic specimen

Table 2 Osseous dimensions of anterior pelvic ring

Study specimen	Cadaver #	Cranial-to-caudal width (mm)	Anterior-to-posterior width (mm)
1	4L	7	8
	4R	8	7
2	5L	n/a	n/a
	5R	n/a	n/a
3	6L	7	7
	6R	6	7
4	7L	8	7
	7R	7	9.5
5	8L	10	7.5
	8R	10	4.5
6	9L	6.5	6.5
	9R	7.5	5
7	10L	8	10
	10R	9	11
8	11L	10	11
	11R	11	10
9	12L	11	12
	12R	12	15
10	13L	12	13
	13R	12	11
Averages		9	9
SD		2	3

possible cortical perforation (Fig. 7c). The second screw's threads perforated the articular cartilage of the superior dome of the acetabulum. This was also noticed during final fluoroscopic examination on the obturator outlet view (Fig. 8). In a live patient, these misplaced screws would have been redirected; however, our goal was to report the accuracy of placing a 6.5-mm screw once we believed to have accurate guide wire placement. In addition, we wanted to evaluate the original articular and cortical perforations after harvest. Two of our specimens had retained total hip arthroplasty components, which did not pose any difficulty (Fig. 9). Overall, 90 % of our screws were accurately and safely placed on first attempt within the anterior pelvic ring using only the described gun barrel view.

Discussion

Percutaneous fixation of pelvic ring injuries has been popularized and refined over the course of last 3 decades [12, 14–18], yet only recently has it gained interest for the treatment of acetabulum fractures. The benefits of percutaneous pelvic and/or acetabular fixation are well described and include accelerated mobilization, earlier weight bearing, potentially decreased operative time, and decreased blood loss and soft tissue dissection

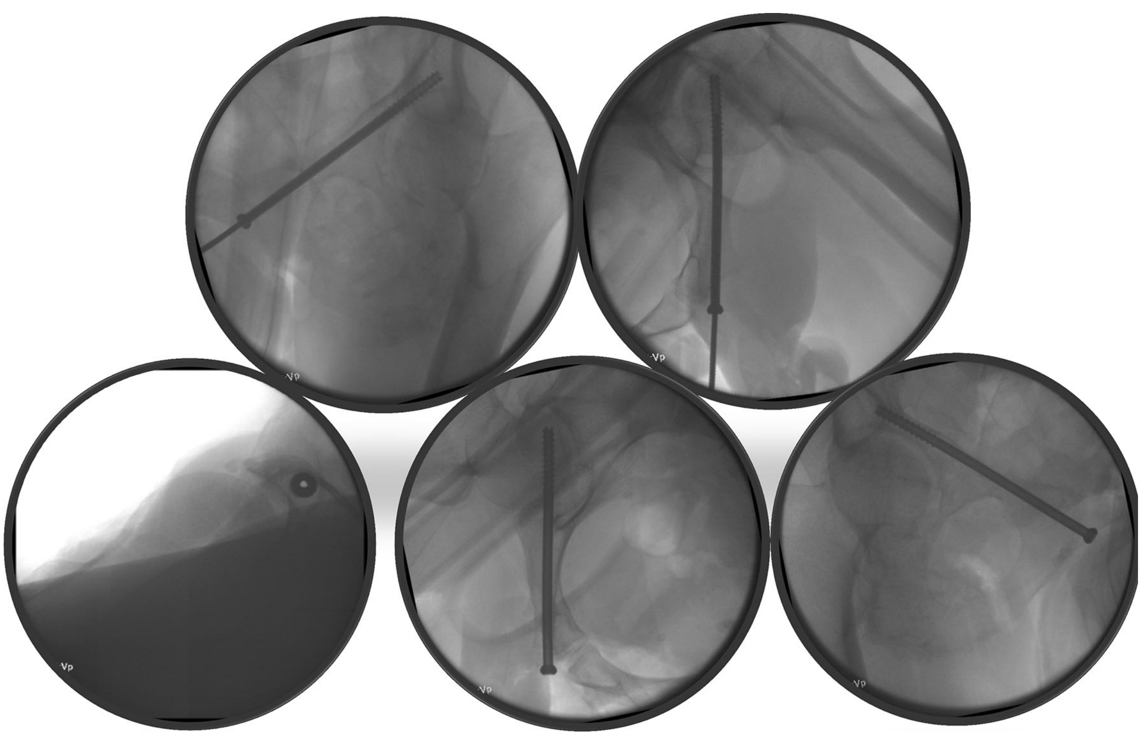

Fig. 6 Pelvic specimen lost to crematorium. *Top* Left side. *Bottom* Right side

Fig. 7 Fluoro pictures of specimen with cortical perforation. *Left* AP pelvis showing acceptable wire position. *Middle* Obturator outlet showing acceptable wire position. *Right* Gun barrel view showing cortical perforation

Fig. 8 Obturator outlet of screw with acetabular perforation

[2, 3, 5, 6, 8–11, 13, 19–26]. Although contraindications to percutaneous fixation exist, such as posterior wall fractures requiring fixation, associated both column fractures and femoro-acetabular loose bodies, one can use the anterior pelvic ring gun barrel view adjunctively for anterior pelvic ring screw fixation when open approaches are employed.

Percutaneous screw placement in the pelvis or acetabulum is technically demanding and requires detailed knowledge of the involved anatomy both in vivo and on imaging studies. Similar to the sacrum, the innominate bones have unique shape and anatomy and thus orthogonal two-dimensional images are not enough for accurate placement of percutaneous screws. If the starting point and/or trajectory are too caudal, the obturator neurovascular bundle is at risk; alternatively, if either is too cranial, then the external iliac vessels are at risk. The roof of the acetabulum is also at risk when placing percutaneous anterior column screws. The osseous corridors of the anterior pelvic ring are narrow and have been studied using various methods. Shahulhameed et al. [9] using 11 pairs of adult cadaveric pelves reported the narrowest cranial-to-caudal dimension at the psoas groove and averaged 15.1 mm (range 12.1–18.2 mm). The same authors also reported a progressive increase in anterior-to-posterior dimension moving laterally from the pubic symphysis to the psoas groove. Puchwein et al. [8] examined three-dimensional reconstructions of uninjured pelves in 50 consecutive polytrauma patients and reported the superior pubic ramus at its narrowest point to be 9.2 ± 2.4 mm, and the average distance from the entry point (of a retrograde screw) to the narrowest point was 50.6 ± 6.3 mm. In comparison, our starting point may

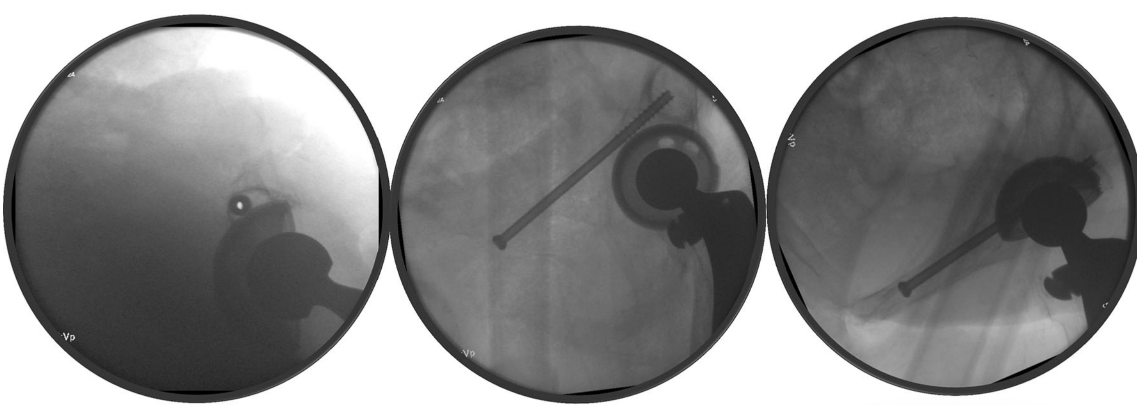

Fig. 9 Anterior pelvic ring screw placed around THA

have been slightly more lateral in order to obtain the appropriate trajectory for purchase in the outer ilium. Similar to any percutaneous fixation technique, the key is an anatomic reduction. The narrow corridor of the anterior pelvic ring potentiates this principle. In our study of 20 cadaveric hemipelvi, we discovered the narrowest cranial-to-caudal dimension occurred adjacent to the acetabular dome ranging from 6.5 to 12 mm with an average of 9 mm, and the narrowest anterior-to-posterior dimension occurred just medial to the iliopectineal eminence, ranging from 5 to 15 mm with an average of 9 mm. Figure 1 demonstrates the radiographic lines and the anatomy each represents. It is not difficult to imagine how the slightest of malreductions will decrease the size of such a narrow bone corridor. In regard to the posterior pelvis, Reilly et al. [27] showed that for iliosacral screw placement, malreductions of 10 mm decreased the intraosseous space available by 40 %. When applied to the anterior pelvic ring, the chance for error increases due to the smaller dimensions. Whether retrograde or antegrade, an intraosseous anterior pelvic ring screw can only be safely placed in the setting of a non- or minimally displaced, or a well-reduced fracture.

Attias et al. [13] evaluated CT reconstructions of 13 patients with acetabulum fractures and found a mean maximum virtual diameter of a retrograde anterior column screw to be 6.4 mm (range 5–7.3 mm), concluding that the cross-sectional diameter measurements cannot accurately predict the maximum diameter of percutaneous screw a column can accommodate. Routt et al. [14] describe using a 200-mm length 2.5-mm drill to place a 3.5- or 4.5-mm screw without a washer for superior pubic ramus fixation. Although our study employed 6.5-mm screws as do other studies, perhaps the safest and most reproducible technique is to use smaller screws, such as a 4.5-mm screw.

Various methods attempting to improve accuracy of percutaneous screw placement in pelvic and acetabular injuries have been and continue to be reported [4, 8, 20–23, 25, 26]. The use of intraoperative CT imaging and navigation has been widely described; however, such tools are not available in all facilities, are costly and require an experienced radiology technician. Gay et al. [4] were the first to report use of CT guidance for percutaneous fixation of acetabular fractures. Lin et al. [21] reported no complications in placing anterior column screws using 2D fluoroscopic-based navigation in three patients. Hong et al. showed successful placement of 21 anterior column and 9 posterior column screws in 18 adult patients [20]. Gras et al. [23] showed 3D navigation may be more accurate than 2D navigation using synthetic pelvic specimens. Ochs et al. used synthetic pelvic specimens to compare conventional fluoroscopy to 2D and 3D fluoroscopic navigation (CV, 2DFN and 3DFN, respectively). Conventional fluoroscopy required higher amounts of radiation and was less accurate than both navigation groups as the 3DFN group had 93 %, 2DFN 80 % and CV 86 % grade 0 perforations according to the system of Gertzbein [22]. Other alternative methods have also been reported using conventional fluoroscopy. Vioreanu et al. [26] reported injecting a radiopaque contrast through a drilled retrograde intraosseous track to confirm safe position without perforation of any cortices or into the joint.

Although we feel confident about our research, it is not without limitation. Due to the cadaver protocol at our institution, screw placement of the pelves was not done in the operating room using standard tables in a supine position. In real surgical practice, percutaneous fixation of the anterior pelvic ring can occur in lateral decubitus or prone positions and our results would need to be extrapolated to accommodate the various patient positions. Also our work involved placing screws in retrograde fashion and did not describe placing antegrade screws in the anterior pelvic ring. The authors have incorporated the described view into their surgical practice with success using either a flat radiolucent table or a fracture table. We have found it best to secure the patients ipsilateral arm across their chest so as to prevent blocking the C-arm. In addition, keeping the x-ray tube as close to the patient's side as possible, for retrograde screw placement (via a Pfannenstiel incision), will allow the maximum space for the surgeon to implant the anterior pelvic ring in retrograde fashion from the contralateral side. Although the view has not been attempted with a patient in prone nor lateral positions, we have found the APR gun barrel view facilitates antegrade screw placement as it allows for locating an optimal starting point, then utilizing inlet and obturator outlet views for trajectory. Due to the position of the C-arm, there is not enough space between the body and x-ray tube to fully place the guide wire. In addition, our sample size is small and a larger sample size would better account for any anatomic variations. Also, our work involved intact pelves. Placing screws in the anterior pelvic ring is certainly more difficult in the setting of a displaced fracture, as reduction maneuvers, open or closed, would be required prior to screw implantation. An anatomic reduction certainly allows for easier interpretation of the APR gun barrel view; however, even in the setting of minimal displacement we have found the view useful in obtaining the starting point, then tapping a drill tip guide wire or reverse drilling a threaded tip guide wire across the fracture site to stay within the narrow osseous corridor. Future research is needed to better evaluate placing screws using the anterior pelvic ring gun barrel view to ascertain in vivo accuracy, surgical time and radiation exposure.

Conclusion

Anterior pelvic screws can be percutaneously placed either retrograde or antegrade. Currently, percutaneous screw placement in the anterior pelvic ring is done while alternating between obturator outlet, inlet and iliac oblique views, allowing for visualization of complex anatomic structures in only a single plane at a time. Such a method is arduous and potentially misleading, as shown with our first reported specimen. The posterior pelvis, akin to the anterior pelvis, involves a non-tubular bone of which each patient has slight variations, difficult to accurately assess on orthogonal views. When placing a percutaneous posterior pelvic screw, the lateral projection provides somewhat of a gun barrel view of the sacral pedicle and allows the surgeon to better assess starting point and trajectory [15]. Applying the same concept to the anterior pelvis, the gun barrel view of the anterior pelvic ring offers the same advantage and has not yet been described in the literature. The fluoroscopic setup is relatively simple, not much different than obtaining a lateral hip image during placement of an antegrade femoral nail, nor does it require extraordinary equipment costs. Based on our results, we found the anterior pelvic ring gun barrel view a safe and reliable method, allowing for accurate placement of anterior column or superior pubic ramus screws.

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Compliance with ethical standards

Conflict of interest None of the authors have any financial, consultant, institutional or other conflicts of interest relevant to this research. Nicholas Quercetti III declares that he has no conflict of interest. Brandon Horne declares that he has no conflict of interest. Zac DiPaolo declares that he has no conflict of interest. Michael J. Prayson declares that he has no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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