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Which radiograph is most accurate for assessing hip joint penetration in infra-acetabular screw placement?

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Abstract

Although infra-acetabular screws have been used for anterior and posterior column transfixation, a screw penetrating the hip joint can result in harmful complications. However, the most accurate intraoperative radiologic imaging tool for identifying articular penetration has not been established. The purpose of the present study was, therefore, to evaluate the consistency with which standard pelvic radiographs compared with computed tomography (CT) can be used for demonstrating articular penetration.

This retrospective review was performed between January 2015 and December 2020. We evaluated the records of patients with acetabular or pelvic fractures who underwent open reduction and internal fixation with infra-acetabular screw placement. We collected demographic data and described infra-acetabular screw placement as follows: ideal placement, articular penetration, and out of the bone. Articular penetration was assessed independently on each pelvic radiograph and compared statistically with the CT scans. Sensitivity, specificity, correct interpretation rate, and prevalence-adjusted bias-adjusted kappa (PABAK) were calculated for each radiograph.

Thirty-nine patients underwent infra-acetabular screw placement. The mean age of patients was 55 years (range, 27–90 years); there were 29 men and 10 women. One patient underwent bilateral infra-acetabular screw placement; therefore, 40 infra-acetabular screws were included in total. Six (6/40, 15%) infra-acetabular screws showed articular penetration on CT and two (2/40, 5%) showed infra-acetabular screws extending out of the bone. Hip joint penetration was correctly identified at a rate of 92.5% (95% confidence interval [CI], 79.6–98.4%) on the outlet view and 87.5% (95% CI, 73.2–95.8%) on the anteroposterior (AP) view. The PABAK for the agreement between pelvic radiographs and CT scans was 0.85 in the outlet view and 0.75 in the AP view.

The outlet view is an accurate method for detecting articular penetration of infra-acetabular screws. We recommend the insertion of an infra-acetabular screw under fluoroscopic outlet view to avoid articular penetration intraoperatively.

Abbreviations: AP = anteroposterior, CI = confidence interval, CT = computed tomography, NPV = Negative predictive value, PABAK = prevalence-adjusted bias-adjusted kappa, PPV = Positive predictive value.

Keywords: acetabular fracture, infra-acetabular screw, pelvic fracture, pelvic radiograph

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1. Introduction

Acetabular fractures are reported to have significant morbidity and mortality due to the high risk of multiple associated injuries, although they constitute only 2% of all fractures.[1–3] With the feature of intra-articular fractures, anatomical reduction should be achieved to avoid post-traumatic osteoarthritis. In addition, stable fixation to allow for early range of motion and weight bearing is critical because insufficient fixation around the pelvis and acetabulum may lead to loss of reduction and failure of osteosynthesis.

Infra-acetabular screws, which were first introduced by Culemann et al in 2011, have been used for the transfixation of anterior and posterior columns.[4] The advantage of infra-acetabular screws has been reported in many biomechanical studies.[5–7] However, infra-acetabular screws must be inserted with caution due to the harmful complications that can result from improper placement, such as a screw penetrating the hip joint or causing injury to the neurovascular bundles.[8,9] According to a study that evaluated the clinical success rate of infra-acetabular screws, 25% were placed in an inappropriate position, including articular penetration or out of the bone.[10]

Although the inlet, obturator-outlet, and iliac-outlet views introduced by Culemann et al have been used to confirm the

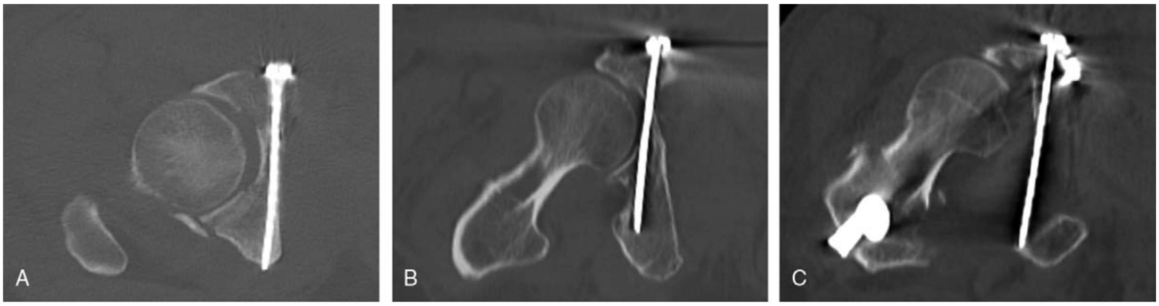

Figure 1. Infra-acetabular screw placement was categorized as ideal, involving articular penetration, or placed out of the bone. (A) Ideal: infra-acetabular screws located between the quadrilateral plate and acetabular fossa; (B) Articular penetration: any evidence of articular penetration; and (C) Out of the bone: screws extending out of the bone.

placement of infra-acetabular screws,[4] we have found, anecdotally, that these views cannot always guarantee the proper position of infra-acetabular screws during insertion because of the complicated and inconsistent anatomic variation of individual patients.[11] Recently, Routt et al reported their experience of improved quality of reduction and implant placement associated with intraoperative 3D imaging, which offers rapid and high-quality real-time computed tomography (CT) images.[12]

However, this new technology is not often available in general institutions, and most still use plain radiography during orthopedic surgery. Fluoroscopic guidance is required to find the infra-acetabular screw corridor intraoperatively; however, the consistency with which plain pelvic radiographs can be used to accurately identify articular penetration of infra-acetabular screws has not been evaluated. Thus, the purpose of the present study was to evaluate the consistency with which plain radiographs could accurately be used to identify hip joint penetration of infra-acetabular screws compared to CT scans.

2. Methods

2.1. Patients

This study was approved by our institutional review board. This single-center, retrospective, observational study was conducted in a university hospital. We evaluated the records of patients with acetabular or pelvic fractures who underwent open reduction and internal fixation between January 2015 and December 2020. We only included patients who underwent infra-acetabular screw placement. Patients with incomplete radiographic and/or clinical data were excluded. Data on demographics and acetabular fracture patterns were collected from medical and radiographic records.

2.2. Evaluation

Standard pelvic radiographs, which included the anteroposterior (AP), oblique (iliac wing and obturator foramen view), inlet, and outlet views, were performed immediately after surgery. A few days later, every patient underwent a postoperative CT to confirm appropriate reduction and implantation. Infra-acetabular screw placement was described as ideal, articular penetration, or out of bone based on CT findings (Fig. 1). Hip joint penetration was assessed independently on each pelvic radiograph. A total of 200 observations (five standard pelvic radiographs in 40 cases) were obtained and reviewed. Articular penetration was defined as an infra-acetabular screw overlapping with the hip joint on plain radiographs (Fig. 2). CT images and radiographs were each read by two independent observers. Disagreements were resolved by consensus between the two investigators or by discussion with a third investigator (a board-certified orthopedic surgeon) when a consensus could not be reached.

2.3. Statistical analysis

Each pelvic radiograph and CT scan were statistically analyzed to determine the consistency with which they could be used to accurately identify infra-acetabular screw hip joint penetration. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and correct interpretation rate were calculated for each radiograph using MedCalc Statistical Software version 19.2.6 (MedCalc Software Ltd, Ostend, Belgium). For the statistical analysis of articular penetration, the disease state was defined as penetration of the infra-acetabular screw, and the non-disease state was defined as proper placement or out of bone status. Sensitivity was defined as the consistency with which the selected radiograph could to be used to correctly identify hip joint penetration when the screw had penetrated the joint (probability of predicting penetration when the screw was penetrated on CT). Specificity was defined as the consistency with which the selected radiograph could be used to correctly identify no penetration of the hip joint when the screw had not penetrated the joint (probability of predicting no joint penetration when the screw was not penetrating the joint on CT scan). Correct interpretation was defined as the proportion of true results, either true-positive or true-negative, in each selected radiograph.

Agreement between plain radiographs and CT images was analyzed using the Cohen kappa coefficient for each pelvic radiograph. The prevalence-adjusted bias-adjusted kappa (PABAK) was calculated considering the prevalence of hip joint penetration, which was not equally distributed bias.[13] All continuous data are expressed as means and standard deviations. Statistical significance was set at $P < .05$, using SPSS version 23.0 (IBM Corp., Armonk, NY, USA).

3. Results

Thirty-nine patients underwent infra-acetabular screw placement (Table 1), and one underwent bilateral infra-acetabular screw placement: one for an acetabular fracture and the other for an AP

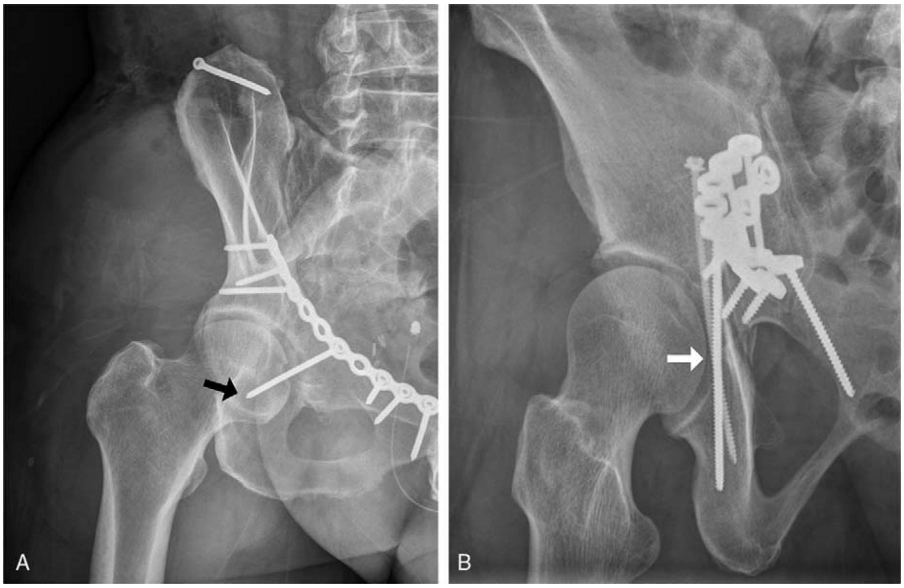

Figure 2. Articular penetration was defined as an overlap of the infra-acetabular screw with the hip joint. (A) In the obturator oblique view, the infra-acetabular screw overlaps with the femoral head (black arrow), and this was defined as articular penetration. (B) Although the infra-acetabular screw is not overlapping the femoral head, it appears to be penetrating the acetabular fossa (white arrow) and was, therefore, classified as articular penetration.

compression injury. Therefore, a total of 40 infra-acetabular screws were inserted. There were 29 men and 10 women, and the mean age at the time of surgery was 55 years (range, 27–90 years). Thirty-three of the 40 infra-acetabular screws (83%) were inserted in acetabular fractures. The most common acetabular fracture type was the column fracture, wherein 23 of the 40 infra-acetabular screws (57%) were inserted, and 7 of the screws (18%) were inserted for pelvic ring injuries.

Thirty-two of the 40 infra-acetabular screws (80%) were placed in the proper location. Six (15%) screws were found to have penetrated the hip joint on CT, and the remaining 2 (5%) were placed out of the bone.

The rate at which the iliac wing oblique view could be used to correctly identify hip joint penetration was 25.0% (95% confidence interval [CI], 12.7–41.2), and the rate at which the obturator oblique view could be used was 42.5% (95% CI, 27.0–59.1). The rate of correct interpretation using the AP view was 87.5% (95% CI, 73.2–95.8) and that using the outlet view was 92.5% (95% CI, 79.6–98.4). The PABAK for agreement between the pelvic radiograph and CT scan was 0.75 on the AP view and 0.85 on the outlet view ($P < .01$). The sensitivity, specificity, PPV, NPV, correct interpretation rate, Kappa coefficient, and PABAK are shown in Table 2.

Table 1

Demographics, fracture patterns and outcomes of the patients (40 infra-acetabular screws; 39 patients).

Parameter	Value
Age (years)*	55 ± 15 (range, 27–90)
Sex*	
Male	29 (74%)
Female	10 (26%)
Side†	
Right	23 (59%)
Left	16 (41%)
Fracture pattern†	
Anterior column	2 (5%)
Anterior column and wall	4 (10%)
Anterior column and posterior hemitransverse	2 (5%)
Both columns	23 (57%)
Transverse	2 (5%)
AP compression	2 (5%)
Lateral compression	5 (13%)
Infra-acetabular screw placement†	
Ideal placement	32 (80%)
Penetration of the hip joint	6 (15%)
Out of bone	2 (5%)

* Calculated based on 39 patients.
† Calculated based on 40 infra-acetabular screws.

4. Discussion

In acetabular fracture surgery, it is essential to ensure that the screws do not penetrate the hip joint. In the present study, the outlet view on plain radiographs and CT images showed a relatively high accuracy and agreement in demonstrating hip joint penetration, although no plain radiographs could be used to completely rule out articular penetration.

To detect screw malposition, various methods of intraoperative projection have been proposed. Some studies have reported that the cross-table lateral view and iliac wing view may be used for ruling out screw penetration in the posterior wall or column and emphasize the use of individualized and tailored radiologic views.[14,15] The use of the inlet-obturator oblique view has been suggested by Tosounidis and Giannoudis to ensure that the screws are not within the joint in both column concomitant posterior wall surgical fixation is required.[16] However, most studies have investigated the use of radiographs for posterior column or wall fractures, and studies on radiograph imaging of infra-acetabular screws have not been sufficient.

To confirm infra-acetabular screw placement, it has been suggested that intraoperative fluoroscopic images be taken in the

Table 2

. Comparison of the accuracy of demonstrating hip joint penetration between pelvic radiographs and CT scans.

	AP	Iliac wing	Obturator	Inlet	Outlet
Sensitivity	50.0 (11.8–88.2)	83.3 (35.9–99.5)	83.3 (35.9–99.5)	33.3 (4.3–77.7)	83.3 (35.9–99.6)
Specificity	94.1 (80.3–99.3)	14.7 (5.0–31.2)	35.3 (19.8–53.5)	94.1 (80.3–99.3)	94.1 (80.3–99.3)
PPV	60.0 (23.9–87.8)	14.7 (10.5–20.2)	18.5 (12.8–26.0)	50.0 (14.7–85.3)	71.4 (38.3–91.0)
NPV	91.4 (82.7–96.0)	83.3 (41.2–97.3)	92.3 (65.5–98.7)	88.9 (81.9–93.4)	97.0 (84.2–99.5)
Correct interpretation	**87.5 (73.2–95.8)**	**25.0 (12.7–41.2)**	**42.5 (27.0–59.1)**	**85.0 (70.2–94.3)**	**92.5 (79.6–98.4)**
P value for Kappa coefficient	< .01	.90	.37	.04	< .01
Kappa coefficient	.47	−.01	.08	.32	.72
PABAK	**.75**	**−.50**	**−.15**	**.70**	**.85**

Data are presented as percentages and 95% confidence intervals.

AP = Anteroposterior, CT = computed tomography, NPV = Negative predictive value, PABAK = prevalence-adjusted bias-adjusted kappa, PPV = Positive predictive value.

following three views: inlet, obturator outlet, and iliac wing-outlet[4]. However, since these views were not consistently accurate due to the anatomic variation of individual patients[11], the infra-acetabular corridor was evaluated on standard pelvic radiographs and compared with that on postoperative CT scans. First, oblique views, such as the iliac wing and obturator views, were associated with low accuracy (25.0% and 42.5%) compared with the other views. Since the infra-acetabular corridor should be placed between the acetabular fossa and quadrilateral plate,[17,18] oblique views cannot present a clear relationship between these structures due to the angle of projection (Fig. 3). Second, the general method used to avoid articular penetration is to make a "perfect dot" in the teardrop in the inlet fluoroscopic view.[19] However, the inlet projection itself is not likely to make this dot because the infra-acetabular corridor may not be parallel to the sagittal plane, as it depends on the entry point and individual corridor. In addition, inlet projection on the articular surface tends to be complicated owing to other implants.

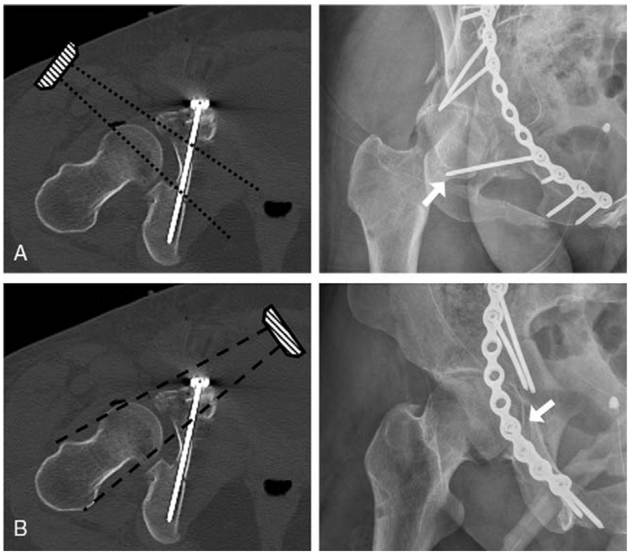

Figure 3. Illustrations and examples of (A) obturator oblique projection and (B) iliac wing projection using reconstructed computed tomography imaging. The beam projected from the anterolateral (obturator oblique, dotted line) and anteromedial (iliac wing, dashed line) sides has the obliquity from the acetabulum and the infra-acetabular screw. Thus, the infra-acetabular screw (white arrow) and acetabulum are overlapping in the oblique view, and therefore, cannot offer reliable information about articular penetration.

In the present study, the outlet view was the most reliable view for detecting articular penetration among the standard pelvic radiographs. An accuracy of 92.5% for the outlet view was calculated from 37 true positive (5) and true negative (32) cases of the 40 cases (37/40) used in this study. The reason for this result is presumed to be that the outlet view is perpendicular to the infra-acetabular corridor considering the angle of projection for each view (Fig. 4). Although the planes of the quadrilateral plate and acetabular fossa are not perfectly parallel to the sagittal plane, the outlet view presented a clear border of this anatomical structure. In clinical situations, radiographic confirmation of the infra-acetabular corridor is essential intraoperatively; therefore, we recommend the use of the outlet view during insertion of the infra-acetabular screw to avoid articular penetration (Fig. 5).

This study has several limitations. First, there were relatively few screws in this study that were classified as articular penetration or out of bone; therefore, the statistical findings should be interpreted with caution. Additionally, interpreting the results was also complicated by the wide CIs for the sensitivity and specificity of each radiograph. Second, there was no consideration of differences that could have occurred in each exam within the same radiograph. Although all pelvic radiographs were examined using the same protocol, it is not likely that the exact same radiograph was taken every time. Finding agreement for each type of radiograph can be an alternative way to overcome this limitation. Third, radiological analyses of the screws out of the bone were not performed due to the small

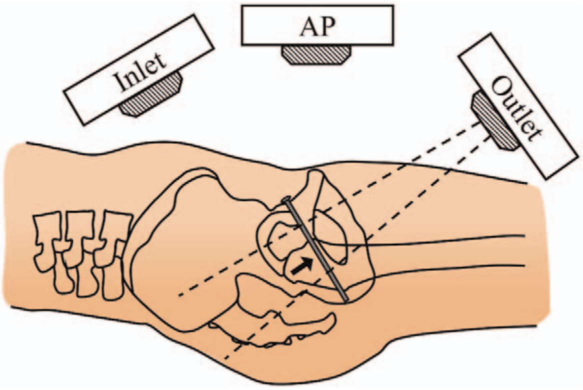

Figure 4. Illustration of the pelvis lateral view with an infra-acetabular screw. The infra-acetabular screw (black arrow) is placed just beneath the acetabulum. The outlet view (dashed line) is likely to be perpendicular to the infra-acetabular corridor than the anteroposterior view.

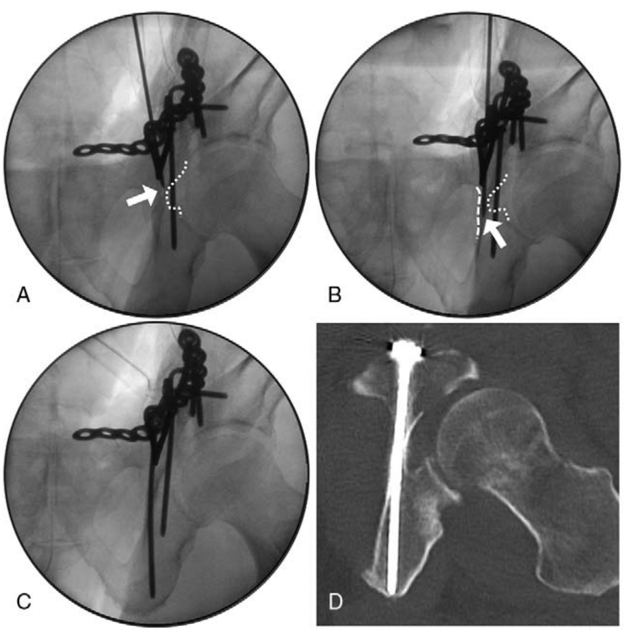

Figure 5. Intraoperative C-arm image during insertion of the infra-acetabular screw in the outlet view. (A) During drilling of the intra-acetabular screw using K-wire, the outlet view clearly shows the medial and lateral boundaries of the infra-acetabular corridor in the coronal plane. The K-wire (white arrow) is being advanced in the direction of the acetabular fossa (dotted line) of the hip joint, and if the K-wire continues to be advanced in this direction, articular penetration could occur. (B) The advancement of the K-wire (white arrow) is altered in a more medial direction under the outlet view to avoid articular penetration and the infra-acetabular corridor is found between the acetabular fossa (dotted line) and the quadrilateral plate (dashed line). (C) The infra-acetabular screw is inserted appropriately between the acetabular fossa and the quadrilateral plate. (D) Postoperative computed tomography scan reconstructed along the infra-acetabular screw demonstrates placement in the appropriate corridor and no articular penetration.

number of cases. Further evaluation with a larger number of cases is therefore required to support our results.

In conclusion, the outlet view was an accurate method to detect articular penetration of infra-acetabular screws. We recommend the fluoroscopic outlet view be used for insertion of infra-acetabular screws to prevent articular penetration intraoperatively.

Author contributions

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Formal analysis: Eic Ju Lim, Wonseok Choi.
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Methodology: Eic Ju Lim, Jae-Woo Cho.
Project administration: Wonseok Choi.
Visualization: Seungyeob Sakong.
Writing – original draft: Eic Ju Lim.
Writing – review & editing: Jae-Woo Cho.

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