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Acetabular Lateral View: Effective Fluoroscopic Imaging to Evaluate Screw Penetration Intraoperatively

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Manuscript Preparation E
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Background: Screw penetration into the hip joint is a severe complication during acetabular fracture surgery. The standard fluoroscopic views of the pelvis cannot provide adequate safety during screw insertion. The aim of this research was to determine and evaluate the accuracy of the acetabular lateral view for screw placement.

Material/Methods: Twenty screws were randomly chosen and intentionally penetrated into the articular surface (1–2 mm), and the remaining 20 screws were extra-articular ones positioned in close proximity to the articular surface. Three surgeons, each evaluating 40 screws, provided a total of 120 rated observations for each screw position. We compared the traditional view or combined with lateral acetabular view with the criterion standard based on unaided visual assessment. A blinded and independent review of each pelvic intraoperative fluoroscopy was made by 3 independent observers. Specificity, sensitivity, positive predictive value, negative predictive value, correct interpretation, intra-class correlation coefficients (ICC), and Youden index were calculated.

Results: There were significant differences in sensitivity, NPV, correct interpretation, and Youden index between the 2 groups (P<0.05). The ICC was 0.531 when the antero-posterior, iliac, and obturator oblique views were used. The ICC was remarkably increased when using a combination of the "lateral" view and the standard views for screw perforation of the joint.

Conclusions: Use of the lateral view of the acetabulum can be a complementary method to identify malpositioned screws, and it helps increase the accuracy rate of inserting screws in the treatment of posterior wall fracture.

MeSH Keywords: Acetabularia • Bone Screws • Radiography

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Background

Posterior wall (PW) fractures, which are also encountered in other mainly posterior-based acetabular fractures, are the most common pattern of acetabular fracture, accounting for approximately one-fourth to one-third of all acetabular fractures [1]. Anatomic reduction and rigid internal fixation are needed to fix displaced acetabular fractures, which require implantation of screws around the articular surface. In view of the unique three-dimensional (3D) anatomic structure, direct visualization of intra-articular screw perforation is possible only through hip dislocation, which is not commonly used in surgical procedures, especially for posterior wall fractures. In this case, screws may be incorrectly placed and penetrate into the hip joint, and this can result in serious consequences such as pain, physical disability, morbidity, post-traumatic arthritis, and surgical revision [2]. To avoid these complications, intraoperative fluoroscopy is commonly used to evaluate the placement of acetabular screws. Screws suspected of violating the articular surface should be identified and revised through numerous images oriented in different planes.

The articular surface is not visible through the Kocher-Langenbeck approach. To obtain essential information on surgical strategy and reduction condition, accurate diagnosis of the pattern of acetabular fracture should be quickly obtained through radiographic assessment before and after the operation, including the anterior-posterior (AP) view and Judet views (iliac and obturator oblique). It is also critical to obtain definitive and representative fluoroscopic images, which is especially important for surgeons making decisions intraoperatively. To promote the accuracy, several techniques have been reported to help surgeons in detecting intra-articular screw penetration with the assistance of intraoperative fluoroscopy [3–7]. Theodoros reported the use of inlet and obturator oblique views for screw placement in PW fractures [7]. Bishop and Yi reviewed the osseous fixation pathways and intraoperative fluoroscopy, provided a detailed description of their clinical applications [8,9]. However, none of these methods are easily performed intraoperatively, and they require the orthopedic surgeon to be extremely familiar with the imaging principles of fluoroscopic views.

Postoperative radiographic evaluation of the hip joint is still used by most orthopedic surgeons as the standard method for evaluating articular reduction and internal fixation placement. Although CT is considered to provide detailed information about fracture pattern, screw position, and reduction to the articular surface of acetabulum postoperatively, findings from postoperative examinations will not eliminate the need for revision surgery if screws are incorrectly inserted. Although 3D fluoroscopy and intraoperative CT are used in some hospitals to treat acetabular fractures, the majority of surgeons in China do not have access to such expensive imaging modalities. The aim of the present study was to determine and evaluate the accuracy of adding of an acetabular lateral view for screw placement intraoperatively, which is particularly helpful for young surgeons with relatively little experience.

Material and Methods

Subjects and fixations

This study was approved by the Regional Ethics Board of our hospital (2017-005-1), and formal consent was obtained. All experiments were conducted at our hospital. A total of 10 cadaveric pelvises were obtained and included in this research. All the specimens were examined prior to this research and were proven to be free from fracture, rheumatism, tuberculosis, tumors, implants, or any condition could have changed it. The cadavers were all males, with an average age of 41 years (range, 25–70 years). All the surgeries were performed by a single surgeon. The screws and reconstruction plates were provided by a single manufacture (Zhengtian, Tianjin, China). The hip joint, proximal femur, surrounding soft tissue, and articular cartilage were removed, but the transverse acetabular ligaments were preserved. All methods were performed in accordance with the relevant guidelines and regulations in our hospital.

A 9-hole reconstruction plate was used to fix on one side of acetabular posterior column. Using a 2.5-mm drill bit, a hole was made along the posterior-superior aspect of the acetabular rim. Two stainless steel screws (3.5-mm) were inserted though the predrilled hole at each end of the plate (proximal screw and ischial screw). Then, the other 4 stainless screws (3.5-mm) were inserted through the predrilled hole (at about 7–11 o'clock of right acetabulum or 1–5 o'clock of left acetabulum) and served as the experimental subjects. A total of 40 experimental screws (excluding the ones located at the end of each plate) were inserted along the posterior wall of the acetabular rim. Twenty screws were randomly chosen and intentionally violated into the articular surface (1–2 mm), and the remaining 20 screws were extra-articular ones positioned in close proximity to the articular surface based on the surgeon's feel (within 2–5 mm) (Figure 1).

Projection technique

The specimens were placed in supine position on a radiolucent table. The longitudinal axis of was parallel to the table and was examined by image-intensifier fluoroscopy. All of them were evaluated with standard AP and Judet radiographs. Different from traditional views, there was no consensus about projection method of lateral views of the pelvis. Because the pelvic structure is wide at the top and narrow at the bottom, it was

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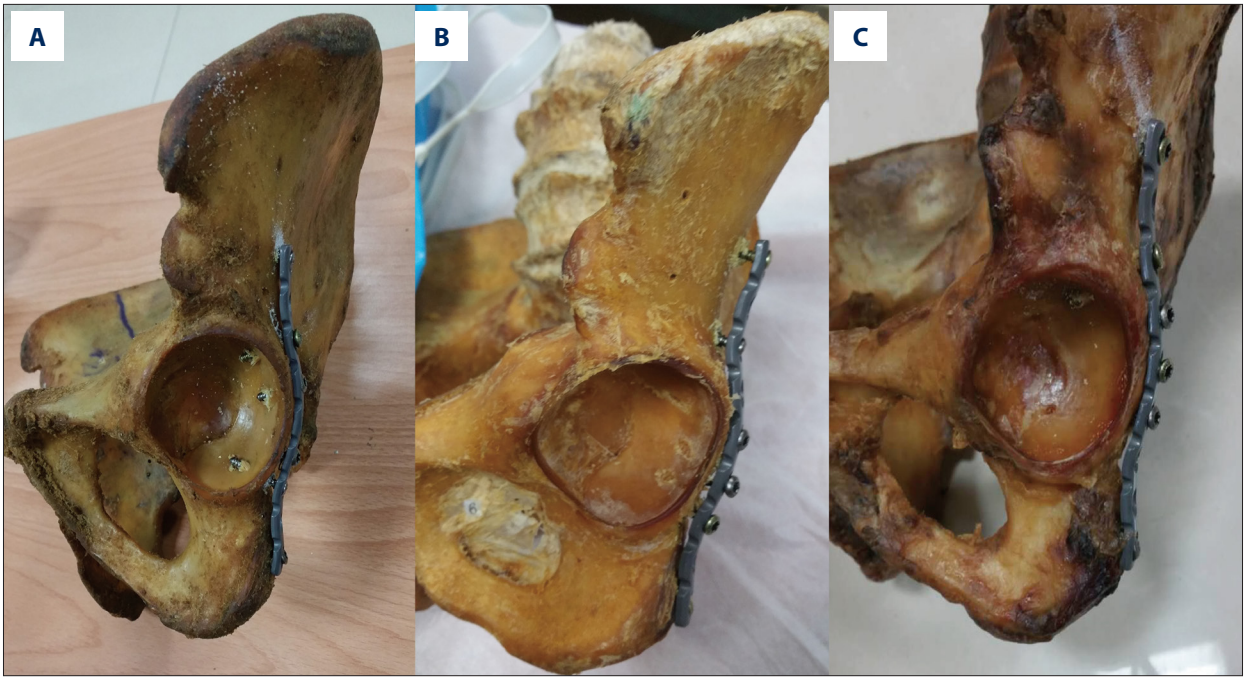

Figure 1. The pelvic model used in the research. (**A**) Three screw tips penetrate into the articular surface by 2 mm in this specimen. (**B**) All screw contained within the bony corridor in this model. (**C**) One intra-articular screw is exhibited in this model.

impossible to completely assess the superposition of the bilateral pelvis with the unparalleled X-rays generated from the tube.

However, in contrast to the lateral view of the pelvis, the anterior and posterior wall of the bilateral acetabular can be super-positioned by adjusting the direction of projection. Starting from a standard "AP" position, the C-arm is further rotated over the patient towards 1 side of the hemipelvis until the projection demonstrates the posterior lips of the bilateral acetabulum are overlapped each other. Then, a curvature that represents the bottom of the acetabulum is clearly shown, and all screws in the plate are separated. Repeated bilateral acetabulum alignment might be necessary after tilting the C-arm in order to obtain a consistent line operatively (Figure 2). This view is called the lateral view of the acetabulum.

Assessment

Data in Group A were categorized according to photographically documented AP and Judet radiographs, and data in Group B were categorized according to photographically documented AP, Judet radiographs, and lateral acetabular views. A blinded and independent review of intraoperative fluoroscopic images of each pelvis was made by 3 independent observers who were all blinded to the true position of screws. They rated radiographs with the antero-posterior, iliac, and obturator oblique (standard) views, first in Group A and then in combination with the corresponding lateral view of the acetabulum in Group B. Before rating Group B, the order of observations was randomized. From 3 surgeons, each evaluating 40 screws, a total of 120 rated observations for each screw position were obtained. Then, the results were compared with the criterion standard based on unaided visual examination (Figure 1). The accuracy of inserted screws and relevant PPV (positive predictive value), NPV (negative predictive value), or other indicators (e.g., sensitivity, specificity, and percent correct interpretations) were all calculated.

The malpositioned screws were the ones that penetrated into the articular cartilage surface (In) of the acetabulum. The well-positioned screws were those that were located within the bone (Out). Sensitivity was defined as the ability of a method to correctly demonstrate screw penetration (predicting when the screw was truly in). Specificity was defined as the ability to correctly demonstrate when the screw did not violate the joint (predicting Out when the screw was truly out). The false-positive rate was defined as 1-specificity, and the false-negative rate was defined as 1- sensitivity. The percent of correct interpretation was defined as the ability of the selected method to accurately determine true screw location. Youden index was also assessed. The ICC was rated as slight (0.0~0.20), fair (0.21~0.40), moderate (0.41~0.60), substantial (0.61~0.80), or almost perfect (0.81~1).

Statistical analysis

Continuous variables are described as the mean values and standard deviation (SD). Frequencies were used to express

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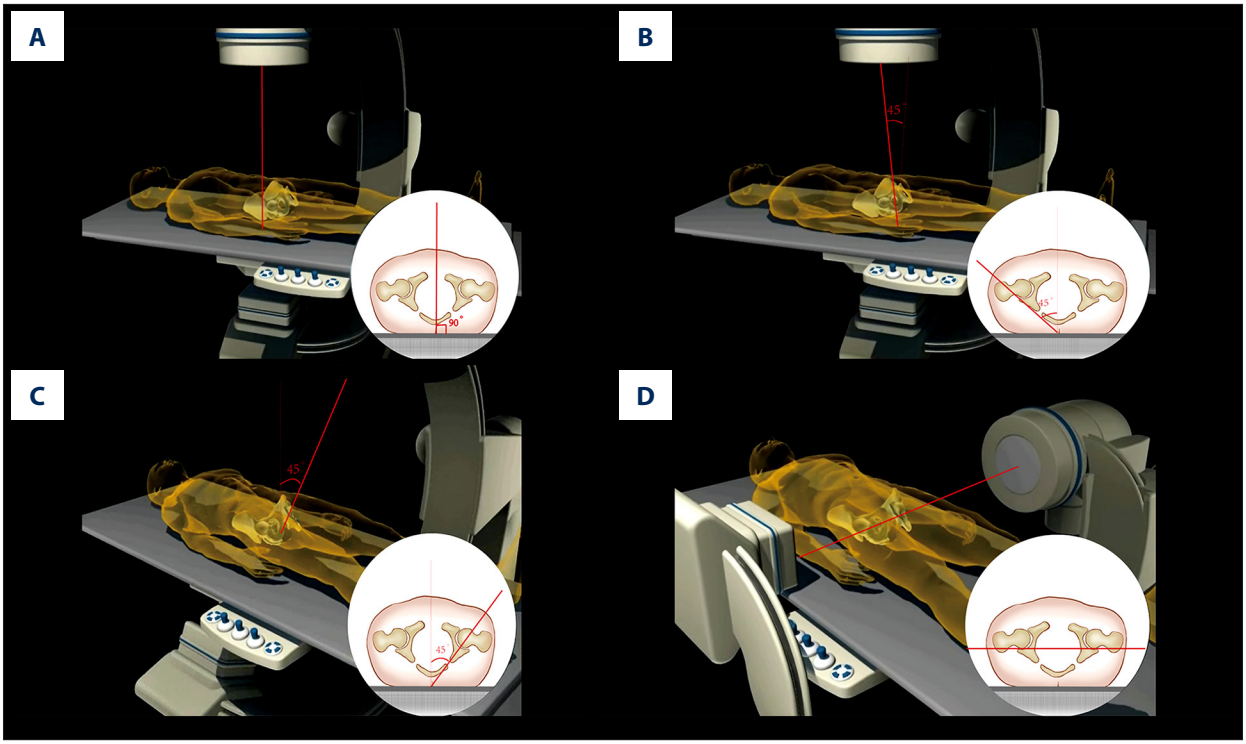

Figure 2. The fluoroscopic projection method of traditional and proposed radiographs used in pelvic model from a mobile fluoroscopy unit. (**A**) Anterior-posterior (AP) view. (**B**) Iliac obturator oblique view. (**C**) Obturator oblique view. (**D**) Lateral view of acetabular which is similar to lateral view of pelvic.

Table 1. The comparison between traditional views and combined with lateral view of acetabular.

	Traditional view	95% CI	Combined with lateral view	95% CI	*P* value
Sensitivity	68.3%	42.3–94.20	88.3%	81.2–95.50	0.046*
Specificity	78.3%	33.4–100.0	91.7%	81.0–100.0	0.184
PPV	72.7%	41.2–100	92.2%	65.8–100	0.127
NPV	69.6%	44.1–95.1	90.3%	79.9–100	0.05*
Correct interpretation	70.8%	42.8–98.8	90.0%	79.2–100	0.046*
Youden index	41.7%	0–97.7	80.0%	58.5–100	0.046*

PPV – positive predictive value; NPV – negative predictive value. * Represent there are significant differences (P<0.05).

categorical data. The statistical analysis was performed with SPSS 21.0 (Version 21, IBM, Armonk, NY, USA). The Pearson chi-square test and the nonparametric Mann–Whitney U test were used to identify significant differences between 2 groups. If more than 20% of the cells had an expected frequency of less than 5, Fisher's exact test was performed. P<0.05 represented a statistically significant difference. The intra-class correlation coefficients (ICC) (two-way mixed, single-measure, absolute agreement) were used to evaluate interobserver agreement about screw position (Version 21, IBM, Armonk, NY, USA).

Results

A view using the posterior lip of the acetabulum radiograph as a landmark was developed. Although not all results with regard to screw position were correct, 3 observers claimed that they were sure about the screw position. The mean value of sensitivity and specificity, PPV, NPV, correct interpretation, and Youden index in the 2 groups are shown in Table 1. Sensitivity and specificity to detect intra-articular screw placement were 68.3% (95% CI, 42.3–94.20%) and 78.3% (95% CI, 33.4–100. 0%) in Group A if only standard views were used, and 88.3%

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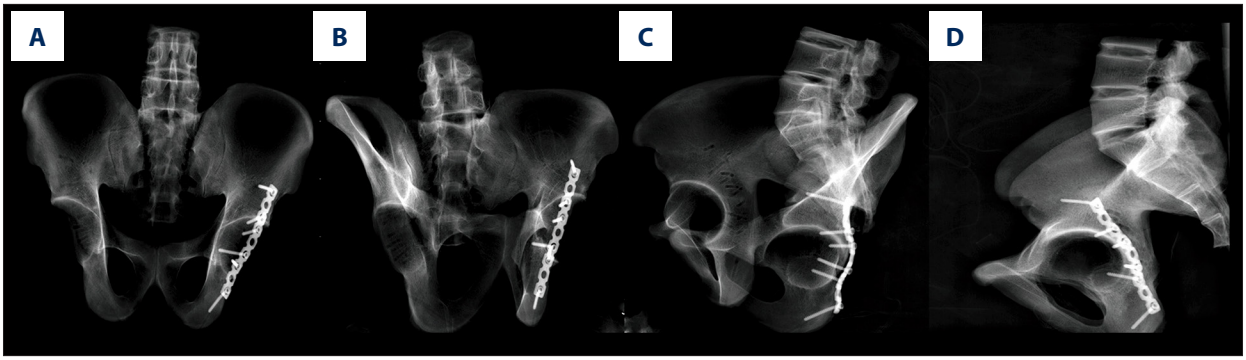

Figure 3. Fluoroscopic images of pelvic models with screws inserted. (**A, B**) The images demonstrate that AP and iliac views are not sufficient to identify the relationship between screws and acetabulum. (**C**) Obturator view shows a false-positive evaluation. (**D**) Lateral view of acetabular exhibits clearly that 3 screws have surpassed the articular surface. These images were presented randomly to 3 surgeons.

(95% CI, 81.2–95.50%) and 91.7% (95% CI, 81.0–100.0%) in Group B when combined with the lateral view. There were significant differences in sensitivity, NPV, correct interpretation, and Youden index between the 2 groups ($P<0.05$). Although there were no significant differences ($P=0.184$), there was a clear trend showing that the combination with lateral view had better specificity than the traditional ones. Difficulty might be encountered during the interpretation with the traditional views familiar in clinical practice; all 3 observers agreed that 4, 8, and 7 screws in Group A failed to demonstrate a space between the screw and articular surface. However, the additional lateral acetabulum view made observers change their decision from false to correct in 10 cases and from correct to false in 0 cases, compared with traditional views.

Interobserver agreement

The ICC was 0.531 (Cronbach's alpha 0.721, 95% CI 0.68 to 0.74) when the antero-posterior, iliac, and obturator oblique views were used. The ICC (0.87, Cronbach's alpha 0.9, 95% CI 0.89 to 0.95) was increased remarkably when using a combination of the "lateral" view and the standard views for screw perforation of the joint. A better result was obvious when rating combined with lateral view (Figure 3). The third observer found an obvious improvement in detecting malpositioned screws when combined with lateral view (Figure 4).

Discussion

The greatest technical difficulty in assessing fixation to the posterior wall of the acetabulum is radiographic evaluation of screw penetration. The clinical outcome of acetabular fracture treatment is affected by restoration of the articular surface, and better reduction means minimized intraoperative and postoperative complications. Intra-articular screw placement is regarded as a severe complication of acetabular surgery; it can lead to internal fixation failure or migration, and development of post-traumatic arthritis, which severely worsens patient prognosis. In the present study, a method using the lateral view of the acetabulum was introduced, which is easy to reproduce using a single radiographic landmark (the posterior cortical wall of the acetabulum) in clinical practice. It is used combined with standard AP and Judet views to identify screws inserting into the posterior column, whether or not they have penetrated into the articular joint. Our results show that it provides an accurate evaluation of malpositioned screws in acetabular surgeries. This enriches our understanding of the anatomical and radiological characteristics of the acetabulum, and is an obvious improvement in the treatment of acetabular fractures.

Since 1960, when the classical theory classifying and defining acetabular fractures through diagnostic radiographs was proposed, routine AP and Judet views have become the most important diagnostic methods used to develop a preoperative strategy and to assess the effects of operations for these complex injuries in clinical practice. Acetabular surgeons always use the C-arm to evaluate reduction of the articular surface and assess the position of peri-articular screws. Although the classical 3 views are traditionally used in evaluating reduction of the articular surface intraoperatively, the result is still unsatisfactory in identifying the malpositioned screws. To solve this problem, different methods of intraoperative fluoroscopy have been reported by several scholars [3–7]. Carmack proposed that the axial and tangential fluoroscopy of screws were comparable in identifying intra-articular screw penetration, but it is difficult to obtain axial and tangential fluoroscopies of each screw [4]. Theodoros proposed that use of the inlet-obturator oblique view could assist placement of posterior wall screws in acetabular fracture surgery [7]. Osterhoff found that the "down the posterior column of the acetabulum" view was a useful addendum in orthopedic trauma surgery, and easily identifies medial perforation or intra-articular

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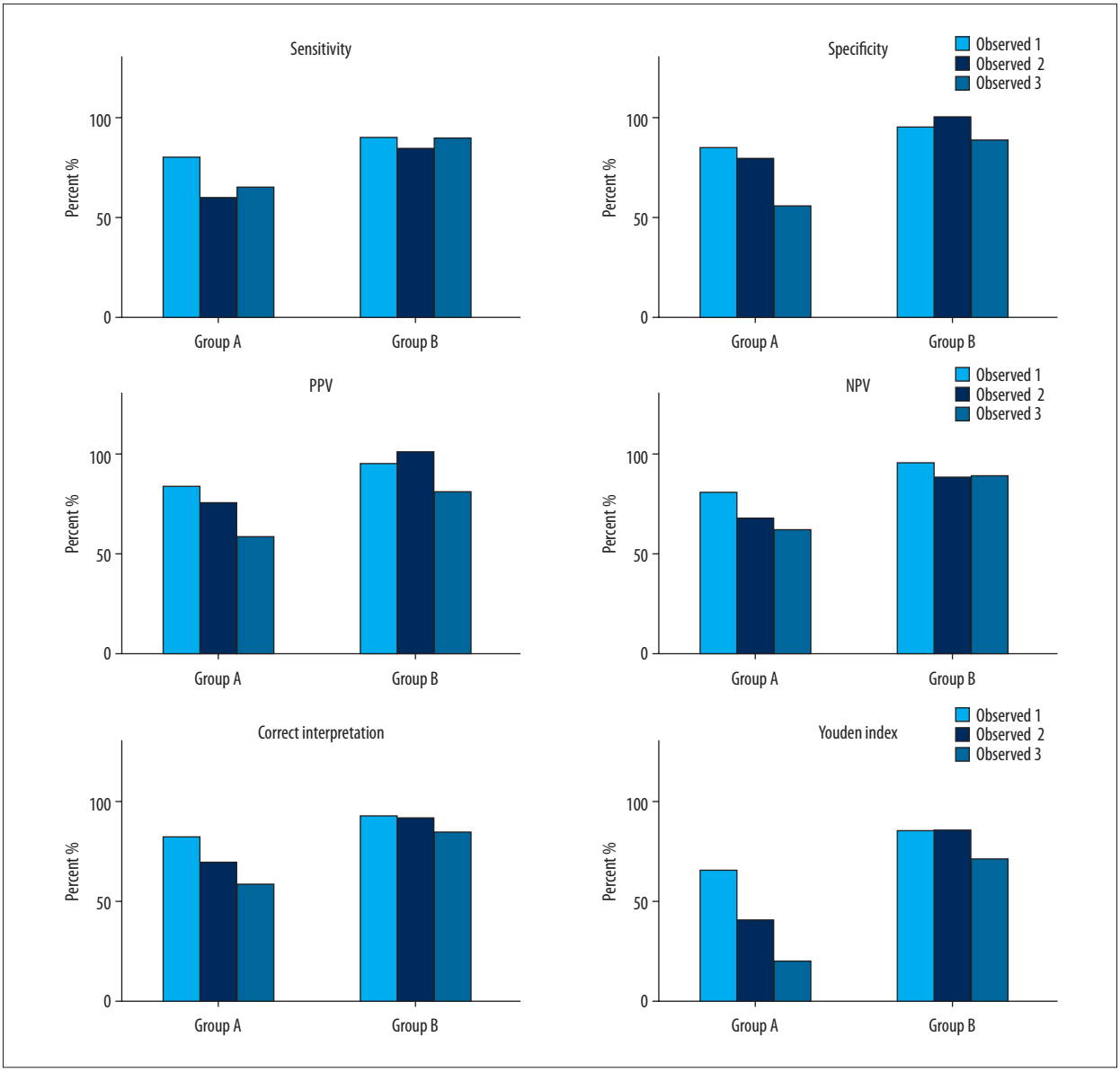

Figure 4. The evaluation results when combined with or without lateral view in 3 observers. The results exhibited that evaluations combined with lateral view were improved in Group B.

implant position combined with routine AP and Judet views [10]. No matter which methods are used, the one that can minimize fluoroscopic time and simplify operations is best.

Our experiences lead us to suggest that the acetabulum be considered as a sphere and the screw as a line; if the line and sphere intersect with each other, no projection direction can be found that shows the sphere and line separated. On the contrary, if the sphere and line do not intersect, although some projections of directions demonstrate possible penetration, at least 1 view will clearly show that they are separated [5]. This means that even if there is only 1 projection direction showing the separation of line and sphere, non-intersection can still be determined. However, performing repeated fluoroscopies to find the intersected direction is harmful, and a more accurate projection in identifying screw placement, called the lateral acetabular view, is proposed to decrease the amount of radiation patients are subjected to. As mentioned before, it is difficult to get a perfect lateral view of the pelvis, but the lateral view of the bilateral acetabulum can be easily obtained. It is extremely helpful to surgeons who treat PW fractures with patients in lateral position, and there is no need to reposition their patients. In the present study, use of the lateral acetabular view combined with traditional methods improved the accuracy of identifying malpositioned screws.

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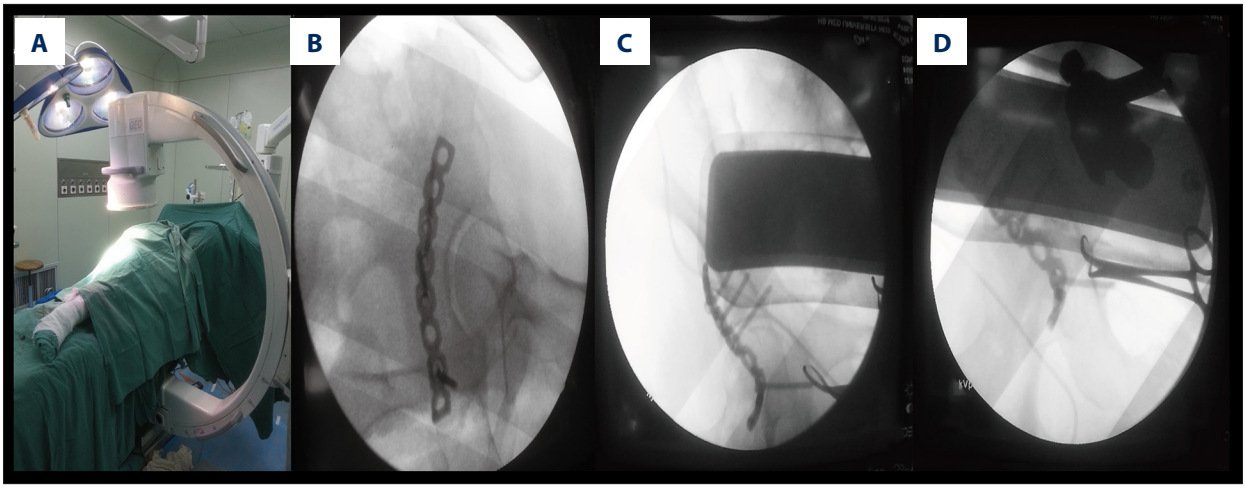

Figure 5. The clinical application of lateral view in acetabular surgery. (**A**) The patient's position was fixed laterally and cannot be changed easily. (**B**) Intraoperative fluoroscopic image with lateral view of acetabulum showed the position of screws, and no one penetrates into articular surface. (**C, D**) fluoroscopic image showed traditional views might be affected by operation table or other assistant equipment such as waist block.

Either of these proposed methods will inevitably have some false-positive and false-negative results, which make it difficult to achieve the desired results if these rates are high. The false-negative results are more problematic than false-positive ones. High false-positive results may lead to prolonged operation time and increased radiation dose. High false-negative rates prevent adjustment of intra-articular screws during the operation, and postoperative pain, joint dysfunction, joint wear, need for a second surgery, and other serious consequences may follow. Our results demonstrated that the sensitivity and specificity were significantly increased when rated combined with lateral views. This means the false-positive rate and false-negative rate are decreased and more improperly inserted screws are identified; therefore, more screws are adjusted promptly and accurately to make sure all of them are located outside the acetabulum.

In the lateral view of the acetabulum, the bilateral acetabular overlap with each other, and form a curved line that represents the bottom of the bilateral acetabulum. A screw fixed in the posterior column can be identified whether or not it protrudes into the articular surface, but it is unclear whether this would be beneficial in clinical practice. Importantly, the effect of soft tissues, intestinal gas, and fat on the radiographic penetration and the quality of image cannot be ignored. In addition, the position of patients on operating table is fixed. To strengthen our research results, acetabular fractures were examined intraoperatively with lateral view. The results were excellent and all screws were confirmed to be without penetration into the acetabulum (Figure 5). However, having just 1 case of operation to verify the feasibility of using the lateral view is insufficient, and we plan to perform further research with more subjects to verify our results.

Our study has certain limitations that should be considered. First, sample size was small and consisted of all male specimens. Second, different surgeons had different levels of surgical skill and expertise in radiographic assessment. Third, the fluoroscopy time may need to be prolonged to find an accurate lateral view, but as surgeons become familiar with this technique, the time needed will be significantly decreased. Fourth, no fracture mimics the treatment of acetabular fractures because the fracture patterns that may lead to a negative effect are not controllable. Despite these limitations, the proposed method for intraoperative evaluation of screw position is feasible and novel, and may have many advantages in clinical practice.

Conclusions

Use of the lateral view of the acetabulum can be a complementary method to identify malpositioned screws, and helps to increase the accuracy of screw insertion in the treatment of posterior wall fractures. There is now a consensus that use of the lateral view provides greater accuracy in evaluation of screw position, and more work enrolling male and female patients will be conducted to verify its clinical value in our subsequent research.

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