Original Article

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Preventing Proximal Radio-Ulnar Joint Screw Penetration during Coronoid Fracture Fixation: A 3D-Digital Modeling and Cadaver Study

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ABSTRACT

Objective: Intra-articular screw penetration is a probable complication of coronoid fracture fixation. The present study aimed to determine the best radiography technique for visualizing the proximal radioulnar joint (PRUJ) space. Moreover, it aimed to determine the safe angle and length of the screw to avoid PRUJ penetration during coronoid fracture fixation.
Methods: The Mimics software was used to construct a three-dimensional model of a healthy man's forearm from a computer tomography scan. It was analyzed using the Solidworks software to determine the X-ray angle that clearly showed the PRUJ space to detect penetration of screws from the coronoid process into the PRUJ and determine the maximum screw angle and length that could be used without intra-articular penetration. To verify these findings, a cadaveric study combined with radiographs was conducted.
Results: To visualize PRUJ space, the optimal X-ray angle was 13º lateral to the perpendicular line when the forearm was positioned at full supination. If the coronoid process was segmented into zones 1 (closest to the radioulnar joint) to 4 (farthest from the joint), the screw could only be inserted at a right angle in zone 1. In zones 2, 3, and 4, inclination angles less than 15, 35, and 60 would prevent intra-articular penetration, respectively.
Conclusions: The X-rays could visualize the PRUJ space with an anteroposterior radiograph at an angle of 13º ulnar deviation from the perpendicular plane. During coronoid process fracture fixation, shorter screws with less lateral inclination were safer when inserting screws in the zones of the coronoid process adjacent to the PRUJ.

Keywords: Screw placement, Coronoid process, Cadaver, Elbow, Computer simulation, Radiography.

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Introduction

One of the challenges in the fixation of the fractures near a joint is intra-articular penetration [1]. Intra-articular penetration of screws can cause significant complications, such as limitation of motion, pain, and arthritis. This problem is more prevalent in some of the peri-articular fracture fixation surgeries, such as fractures of the proximal humerus [2], distal radius [3], acetabulum [4], femoral neck [5], and ankle [6]. One of the less prevalent fractures in which surgeons face similar challenges is coronoid process fracture. The screw might penetrate the proximal radio-ulnar joint (PRUJ) during screw fixation of coronoid process fracture. The radial head is surrounded by the radial notch of the ulnar bone. When we insert a screw or pin adjacent to PRUJ there is a risk of screw penetration to this joint space. Such complications can happen during open reduction and internal fixation (ORIF) of the proximal part of the ulna such as coronoid, olecranon, or proximal ulnar shaft fractures. Several recommendations were provided to detect intra-articular penetration of the screw during surgery, including the presence of a block or crepitus sensation in the joint motion [7] or the use of innovative navigation-guided systems [8]. Intra-operative fluoroscopy in different angles, as well as a CT scan, are preferred procedures that could objectively identify such screw mal-position [9]. However, taking multiple radiographs exposes both the patient and the surgeon to more ionizing radiation [10, 11]. Due to the natural morphologies of the radial head and radial notch of the ulna, in standard radiographic views of the elbow joint, there is an overlap of the coronoid process on the radial head, and the PRUJ space is not clearly visible. To eliminate this overlap, it is necessary to tilt the X-ray beam from the standard AP and lateral beam angles.

Determining an optimal radiologic view decreases the need for multiple radiographs. To the best of our knowledge, no studies have been conducted to determine the optimal radiographic view for visualizing the PRUJ screw penetration. In this way, the present study aimed to identify the optimal X-ray angle for visualizing the ulnar aspect of the PRUJ to assess screw penetration. Moreover, using computer simulation, the maximum screw length and angle that could be used without the screw penetrating the PRUJ was calculated. Then, in a cadaver study, the findings were examined by applying screws with different lengths and angles in the coronoid process. Besides, the occurrence of intra-articular penetration was assessed using radiographs and direct inspection.

Materials and Methods

This experimental study was conducted in two phases: a three-dimensional model study and a cadaver study.

Three-dimensional Digital Model Study

For three-dimensional (3D) modeling, a forearm computer tomography (CT) scan of a healthy man volunteer was used. The CT scan comprised the elbow and wrist joints at complete supination on an even surface parallel to the coronal plane of the body. This CT scan served as the reference for creating a 3D model using Materialise's Interactive Medical Image Control System (MIMICS) software (Materialise, Leuven, Belgium) (Figure 1A). The 3D model was then exported to Solidworks Premium software (Dassault Systemes, Solidworks Corps, USA), for analysis. Solidworks software analyzed the 3D model to recommend the length and angle of screws. The angle was calculated so that the ulna, which abuts the PRUJ (the radial notch of the ulna), could be seen clearly and without obstruction. This angle was determined by drawing a tangential line to the radial notch of the ulnar bone in its cross-section at the level of its articulation with the radial head. It was hypothesized to correlate with a reproducible radiographic angle for visualizing PRUJ intra-articular screw penetration. To establish areas of the coronoid process that could suitably represent possible screw insertion points, the following steps were performed. First, the part of the ulna contained the coronoid process and PRUJ was determined. Then, this part of the ulna was divided into multiple transverse slices. Three transverse sections were the most restricted sites for screw insertion. In other words, they provided less free space in the coronoid bone, adjacent to the PRUJ for screw insertion. Therefore, it was decided to include these three sections for analysis (Figure 1B). Dimensions of each section were calculated, and the reference transverse plane was determined by selecting a section that was closest to the mean of these dimensions (Figure 1C). Then, the coronoid process was divided into four areas at the sagittal plane (Figure 2). The coronoid process was divided into four zones, regarding the possible number of size 3.5 mm screws that could be inserted in the coronoid process. In each of these areas, as well as at the level of the reference transverse plane, the maximum length (diameter from anterior to posterior cortex) of the screw and angles (degree of radial deviation from the perpendicular line to the horizon) that would prevent the screw from penetrating the joint were determined. To avoid confusion, only the maximum screw angle and length were reported. The screw's trajectories were considered parallel to the transverse plane, which meant that the screw had no deviation to the proximal or distal portions of the limb.

Cadaver Study

Eight upper limbs from four fresh male cadavers were selected. The cadavers were aged between 18 and 70 years old, with no obvious gross scars or deformities in their elbows. All procedures were carried out by a postgraduate fourth-year (PGY-4)

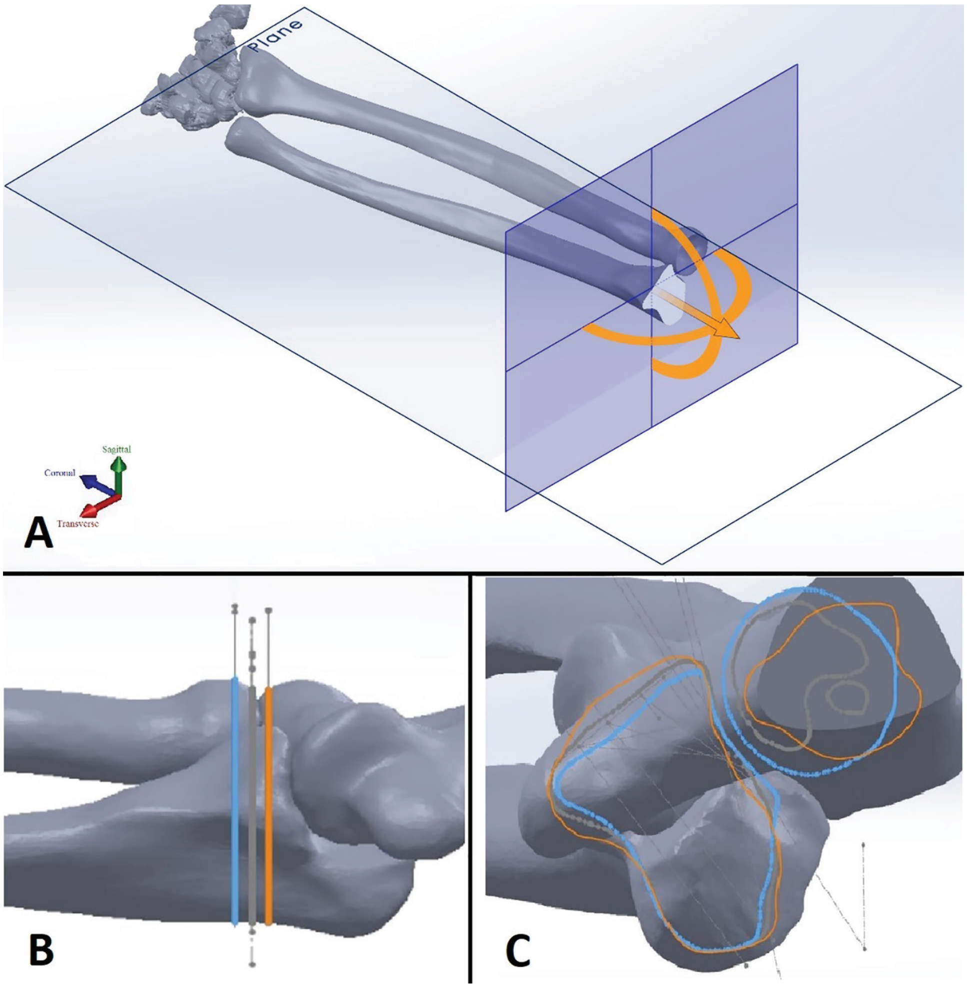

Fig. 1. The 3-dimensional model of elbow, forearm, and wrist simulated from forearm CT scan of a healthy man using MIMICS software. The spatial planes and the full-supination position of the forearm were revealed (A). Three transverse sections of the ulna on the coronoid level were drawn (B), and a section closest to their average was used as the reference transverse plane (C).

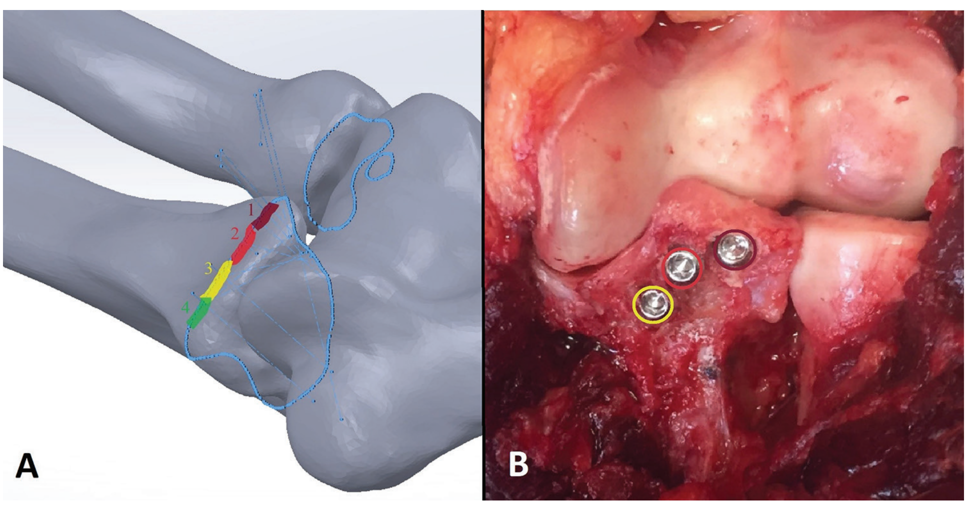

Fig. 2. The coronoid process was divided into four equal zones from radial to ulnar side (A). Screws were inserted in zones 1, 2, and 3 of the coronoid process of the cadaver model (B).

orthopedic surgery resident. The study was performed according to the human tissue storage and use policy for scientific research. The investigation was approved by the local Ethics Committee of Shiraz University of Medical Sciences, Shiraz, Irfan (code: IR.SUMS.MED.REC.1401.177). Written informed consent was obtained from the first-degree relatives of the deceased people if they were available. The elbow specimens were fixed in full supination position. After dissection, screws (size 3.5 mm) were inserted in different zones of the coronoid processes of the specimens, regarding the length and angle recommended by the software (Figure 3). A goniometer was used to determine the radial deviation angles of the drill bit (size 2.7 mm). Screws with larger angles and lengths were also placed.

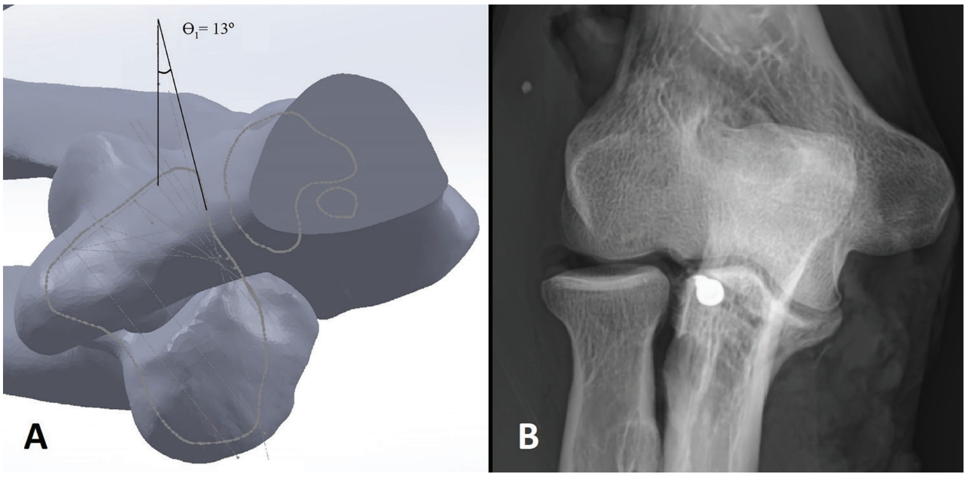

Fig. 3. The angles of X-ray illumination that best visualize the proximal radioulnar joint and possible screw penetration points out of the coronoid process. This angle was found by drawing the tangential line to the radial notch of the ulnar bone in its cross-section at the level of its articulation with the radial head (A). The proximal radio-ulnar joint is clearly visible in an X-ray radiograph of the cadaver model with an illumination angle of 13° radial deviation (B). It shows no intra-articular penetration of the screw inserted at a right angle in zone 1 of the coronoid process (B).

Table 1. Maximum possible lengths and angles of screw insertion in each zone of the coronoid process to avoid its intra-articular penetration using 3-dimensional digital simulation

Coronoid process zones from radial to ulnar side	Radial deviation angle of screw (α), degrees	Maximum applicable screw length, mm
1	α=0°	NL
2	α=0°	NL
	0°<α<15°	18
3	α<15°	NL
	15°<α<35°	18
4	α<30°	NL
	30°<α<50°	20
	50°<α<60°	18

NL: no limitation (the screw does not penetrate the proximal radio-ulnar joint regardless of its length); mm: millimeters

Finally, the radioulnar joints were evaluated for any penetration using both plain X-rays and direct inspection.

Results

The 3D modeling analysis identified the angle of the incidence or illumination (hereafter Θ angle). It is defined as the angle between the X-ray and a line perpendicular to the coronal plane. In the anteroposterior view, the best X-ray Θ angle to visualize the PRUJ was determined at 13º to the lateral of the perpendicular line to the coronal plane when the forearm was placed at full supination on a completely even surface (Figure 3). Using sagittal incisions, four areas along the width of the coronoid process were created (Figure 2). It was revealed that entering screws in an orthogonal fashion (90°) to all areas would not result in penetration, even when using long screws. In zone 1, any deviation would result in intra-articular penetration. In zone 2, from 0º to 15º, screws with a maximum length of 18 mm would not penetrate the joint. In zone 3, from 0º to 15º, there was no maximum screw length. However, from 15º to 35º, 18 mm was the maximum acceptable length. In zone 4, from 0º to 30º, there was no risk of intra-articular penetration; from 30º to 50º, a maximum length of 20 mm was permissible. From 50º to 60º, an 18 mm screw could be inserted without penetrating the joint (Table 1 and Figure 2).

In the cadaver study, the findings of the first phase were tested. First, screws up to 30 mm in an orthogonal fashion in zones 1, 2, and 3 of the coronoid process were inserted (Figure 2B). This resulted in no penetration, verified by direct inspection of articular cartilage after dissection of the joint. An 18 mm screw with an angle of more than 15º inserted in zone 2 resulted in intra-articular penetration (Figure 4). A 22 mm screw inserted at zone 3 with an angle of less than 15º did not penetrate the joint. Finally, the X-rays were taken at Θ angle of 13º in complete supination. In cadavers with no penetration, radiographs showed a clear joint space (Figure 3B). In three cadavers with intra-articular screw penetration, X-rays successfully visualized the penetration (Figure 4C).

Discussion

The coronoid process contributes to elbow stability

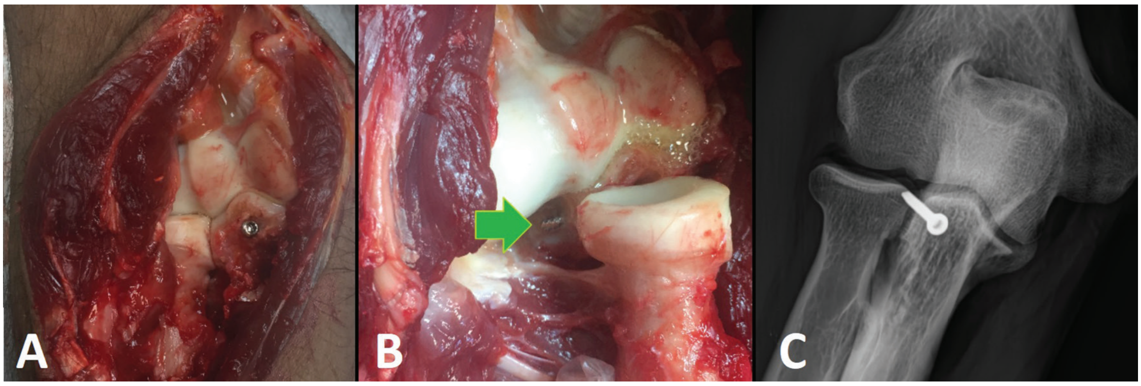

Fig. 4. An 18 mm screw in zone 2 of the coronoid process of the cadaver model (A). The mentioned screw penetrated the proximal radio-ulnar joint space when inserted at an angle of more than 15° (B). An Antero-posterior X-ray radiograph of the mentioned cadaver model in full supination position of the forearm with an illumination angle of 13º radial deviation. It shows intra-articular screw penetration (C).

as a buttress that prevents posterior displacement of the ulnar bone on the distal of the humerus. Isolated fracture of the coronoid process is infrequent, and it is usually associated with concomitant radial head fracture, elbow ligamentous injuries, or elbow dislocation [12]. O'Driscoll *et al.,* described a classification system for coronoid fracture based on the size, pattern, and mechanism of injury [13]. They classified coronoid fractures into three main types, tip (type I), anteromedial facet (type II), and basal fractures (type III). The coronoid fractures are managed based on their fracture pattern, as well as other concomitant osseous and ligamentous injuries of the elbow. Coronoid tip fractures are treated by restoring the capsular buttress using pull-out sutures from the anterior capsule and its avulsed bony fragment through osseous tunnels in the ulna [12]. In types II and III, ORIF of coronoid fracture is indicated using screws alone or with buttress plates [14, 15]. Screws could be inserted in anteroposterior or posteroanterior directions. The medial approach is preferred for ORIF of coronoid fractures in type II and type III (without olecranon fracture) [12]. This determined the radial deviation trajectory of screws, which could increase the chance of screw penetration during ORIF of coronoid fractures. The accuracy of screw insertion could be enhanced by utilizing cannulated screws or by applying an anterior cruciate ligament type of drill guide. Furthermore, potential joint penetration of screws could be detected by feeling the crepitus in joint motion or by using proper intra-operative imaging.

There are few applied anatomical studies dedicated to screw fixations adjacent to the elbow joint. In a cadaver study, Githens *et al.,* used radio-opaque wires to designate the articular facets and the central trochlear ridge of the proximal ulna [16]. Additionally, the zones at risk for screw insertion during olecranon fixation were identified. In another cadaver study by Gray *et al.,* the best site for placement of screws for radial head fractures was determined to avoid intra-articular penetration [17]. Dizdarevic *et al.,* assessed intra-articular screw penetration during the radial head and olecranon locking plate fixation in a cadaver study [18]. However, to the best of our knowledge, no such investigation has been conducted about the anatomy of the PRUJ in coronoid screw fixation.

In addition to standard orthopedic radiographic views, several special radiographic views highlighted a specific anatomic structure or pathology. For the elbow joint, besides anteroposterior and lateral views, an oblique view is used to avoid over-shadowing of the ulna on the radial head. However, no such radiographic view is described to visualize the PRUJ articular surface of the proximal ulna. In the present study, an X-ray angle that optimally visualized the PRUJ was determined. This could be applied to avoid intra-articular screw placement during coronoid fracture fixation. Moreover, we recommended maximum angles and lengths of the screws that could be used without penetrating the joint.

Thirteen-degree ulnar deviation of the X-ray beam when the forearm is in complete supination could show the PRUJ space. Determining this standard illumination angle could lessen the need for taking several intraoperative radiographs and, in turn, the patient's total radiation exposure. We also verified that when the point of screw insertion was the most lateral (closest to the joint space), there was almost no room for the inclination of the screw. Surgeons should be aware to insert the screw completely perpendicular to the horizon or choose more lateral points of entry wherever possible. Accordingly, the more lateral the point of entry moves, the wider zone of safety is expected in both angling and the length of the screws. Although it is evident that screws near a joint are more likely to penetrate the joint space, the findings of the present study provided the maximum allowed angles and lengths of the screws. This could help provide guidance and reduce the need for trial and error with multiple screw insertions. This study could serve as a preliminary report for developing guidelines about screw insertion into the PRUJ. Future studies are recommended to investigate the findings of this study in other demographics, such as women, children, and people of different ethnicities.

This study simulated ORIF of coronoid fixation using screws with anteroposterior direct and not posteroanterior directed screws. As a result, the recommended length and angles might not be applicable to posteroanterior directed screws. However, the suggested X-ray beam is still helpful for inspecting the PRUJ for screw penetration. The present 3D digital and cadaver models belonged to adult males. Previous studies found that the coronoid process dimensions were different between men and women [19]. Therefore, the results of this study cannot be generalized to the female and pediatric populations. Accordingly, since this study does not consider anatomical variations, these findings might not be generalizable to different body types or ethnicities. Finally, the present results were produced with the prerequisite that the screw had no deviation distally or proximally (angle between the screw and the transverse plane=0º), and that the forearm was positioned in complete supination. However, in practice, surgeons attempted to insert the screw perpendicular to the fracture plane. Since the fracture plane might face any direction, the surgeon might prefer to insert the screws with a more proximal or distal angle. Furthermore, during the procedure, the limb was manipulated and repositioned frequently, which made it difficult for the surgeon to determine the angles. Besides, it was not possible to assess which method of screw fixation could provide a more stable fixation. Thus, we just focused on the angle of screws and their length.

The optimal X-ray angle for assessing the PRUJ was 13° ulnar deviation of the X-ray beam when the forearm was in complete supination. When fixing a coronoid process fracture, shorter screws with less lateral inclination should be utilized in the coronoid process zones closest to the radio-ulnar joint.

Declaration

Ethical approval for study: The investigation was approved by the local ethics committee (code: IR.SUMS.MED.REC.1401.177).

Conflict of Interest: The authors do not have any potential conflicts of interest concerning this manuscript.

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Informed consent: Informed written consent was obtained from the first-degree relatives of the deceased people if they were available.

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References

1. Sridhar MS, Hunter MD, Colello MJ. Periarticular screws: what's in and what's out of the joint? *BMC musculoskeletal disorders*. 2022;**23**(1):1-11.
2. Li B, Xiong W, Chang S. Research progress on intra-articular screw penetration in proximal humeral fracture treated with locking plate. *Zhongguo xiu fu Chong Jian wai ke za zhi= Zhongguo Xiufu Chongjian Waike Zazhi= Chinese Journal of Reparative and Reconstructive Surgery*. 2021;**35**(4):403-408.
3. Klein JS, Mijares MR, Chen D, Orbay JL, Landy DC, Owens PW. Radiographic evaluation of the distal radioulnar joint: technique to detect sigmoid notch intra-articular screw breach in distal radius fractures. Techniques in Orthopaedics. 2020;**35**(1):73-77.
4. Hoehmann CL, DiVella M, Osborn NS, et al. Excessively long interfragmentary screws for posterior wall acetabular fractures can predict intra-articular penetration. *Orthopaedics & Traumatology: Surgery & Research*. 2022;**108**(2):103202.
5. Kumar A, Jameel J, Qureshi OA, Kumar M, Haider Y, Das S. Modified radiographic views to prevent the anterosuperior and posterosuperior bony violation during screw fixation of femoral neck fractures. *European Journal of Orthopaedic Surgery & Traumatology*. 2021;**31**(3):459-464.
6. Giordano V, Gomes AF, Amaral NP, Albuquerque RP, Pires RE. Preventing surgical complications: A survey on surgeons' perception of intra-articular malleolar screw misplacement in a cadaveric study. *Patient Safety in Surgery*. 2011;**5**(1):1-5.
7. Anglen JO, DiPasquale T. The reliability of detecting screw penetration of the acetabulum by intraoperative auscultation. *Journal of orthopaedic trauma*. 1994;8(5):404-408.
8. Karkenny AJ, Mendelis JR, Geller DS, Gomez JA. The role of intraoperative navigation in orthopaedic surgery. JAAOS-Journal of the American Academy of Orthopaedic Surgeons. 2019;**27**(19):849-858.
9. Takemoto RC, Gage M, Rybak L, Zimmerman I, Egol KA. Accuracy of detecting screw penetration of the radiocarpal joint following volar plating using plain radiographs versus computed tomography. *Am J Orthop (Belle Mead NJ)*. 2012;**41**(8):358-361.
10. Zhang L, Lin G, Yang G, et al. Multiple radiographic projections in detecting intra-articular screw penetration during fixation of femoral neck fractures. *Orthopedics*. 2014;**37**(10):e885-e891.
11. Rashidifard C, Boudreau J, Revak T. Accuracy of posterior wall acetabular fracture lag screw placement: correlation between intraoperative fluoroscopy and postoperative computer tomography. *Journal of Orthopaedic Trauma*. 2020;**34**(12):650-655.
12. Budoff JE. Coronoid fractures. The Journal of hand surgery. 2012;37(11):2418-23.
13. O'Driscoll SW, Jupiter JB, Cohen MS, Ring D, McKee MD. Difficult elbow fractures: pearls and pitfalls. Instructional course lectures. 2003;**52**:113-34.
14. Lanzerath F, Hackl M, Wegmann K, Müller LP, Leschinger T. The treatment of anteromedial coronoid facet fractures: a systematic review.

Journal of Shoulder and Elbow Surgery. 2021;30(4):942-8.

15. Lor KKH, Toon DH, Wee ATH. Buttress plate fixation of coronoid process fractures via a medial approach. Chinese Journal of Traumatology. 2019;**22**(5):255-60.

16. Githens TC, Campbell ST, Salazar B, et al. Understanding the Radiographic Anatomy of the Proximal Ulna and Avoiding Inadvertent Intraarticular Screw Placement. *Journal of Orthopaedic Trauma*. 2020;**34**(2):102-107.

17. Gray R, Hoekzema N, Rubio F, et al. Avoiding articular breakthrough in screw fixation of radial head fractures. *JSES International*. 2022.

18. Dizdarevic I, Eden CM, Bengard M, Barron OA, Catalano III LW, Glickel SZ. Assessment of intra-articular screw penetration during radial head and olecranon locking plate fixation: a cadaveric study. *Hand*. 2016;**11**(1):65-71.

19. Matzon JL, Widmer BJ, Draganich LF, Mass DP, Phillips CS. Anatomy of the coronoid process. *The Journal of hand surgery*. 2006;**31**(8):1272-1278.