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Skyline view versus intraoperative 3D fluoroscopy for dorsal screw protrusion identification following volar plating in the treatment of distal radial fracture

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Abstract

Background Dorsal screw protrusion can lead to complications such as extensor pollicis longus (EPL) tear or rupture after volar locking plate (VLP) fixation. Previous studies displayed that intraoperative 3D fluoroscopy and skyline view had similar diagnostic accuracy. This study investigated the efficacy of intraoperative 3D fluoroscopy compared to skyline view for detecting dorsal cortex screw protrusion in VLP procedures for unstable intra-articular distal radius fractures (DRF). We used postoperative computed tomography (CT) to assess the efficacy and addressed the limitations of previous methods in evaluating screw penetration accurately.

Methods We utilized the ICUC database, a prospective cohort of patients with surgically treated DRF, to collect cases with available images, including skyline views, intraoperative 3D fluoroscopy, and postoperative CT scans. The postoperative CT confirmed whether the screw protruded through the dorsal cortex. The interrater reliability was assessed using Cohen's Kappa, and a diagnostic test was utilized to compare the two intraoperative imaging modalities.

Results Twenty-one unstable DRFs were included in the study. The agreement between skyline view and postoperative CT was moderate agreement, with a kappa value of 0.481 (95% CI: 0.297–0.652, $N=84$), identifying 10 uncertain, 56 shorter screws, and 18 screw penetrations. Intraoperative 3D fluoroscopy demonstrated almost perfect agreement with postoperative CT, with a kappa of 0.839 (95% CI: 0.703–0.975, $N=84$), identifying 62 shorter screws and 22 screw penetrations. The sensitivity and specificity of intraoperative 3D fluoroscopy in detecting dorsal screw protrusion were 81.8% and 98.4%, respectively, while the skyline view's sensitivity and specificity were 72.2% and 90.9%.

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Conclusion 3D fluoroscopy offers an almost perfect evaluation, whereas the skyline views provide only moderate agreement. 3D fluoroscopy could reduce cumulative radiation exposure of surgeon and patient compared to skyline view. Clinically, 3D fluoroscopy would be beneficial for surgeons to evaluate dorsal screw protrusion precisely and safely.

Keywords Screw protrusion, Distal radius fracture, 3D fluoroscopy, Skyline view, Dorsal tangential view

Background

Distal radius fracture (DRF) is one of the most common fractures in the upper extremity [1]. The incidences of DRF in males and females ranged from 100 to 190 per 100,000 population/year and 282–458 per 100,000 population/year, respectively [2]. Open reduction and internal fixation with a volar locking plate (VLP) are increasingly used as surgical treatment for unstable intra-articular DRF [3, 4]. Although VLP can restore distal radius alignment and own favorable outcome, the rate of complications ranged from 3 to 36% with VLP fixation of DRF [5, 6]. Dorsal screw protrusion, one of the perioperative complications, might be hidden by Lister's tubercle on the lateral view [7] and thus increase the risk of extensor tendon irritation and subsequent tendon rupture [8]. Therefore, intraoperative evaluation of screw position was important [9].

Intraoperative detection of screw protrusion can give orthopedic surgeons a chance to change or adjust the screw length to prevent screw penetration-related complications [10, 11]. Conventionally, anteroposterior (AP) and lateral anatomical tilt views were used intraoperatively to gain insight into how each screw captures the fracture fragments properly [11, 12]. Additionally, the dorsal tangential view, known as the skyline view, can help detect dorsal screw protrusion [13]. According to cadaveric and clinical studies, accurate assessment of screw protrusion could be identified through skyline view [14–16]. Two studies investigated the accuracy of skyline view by using postoperative computed tomography (CT) as the reference standard, and the prevalence of dorsal screw protrusion was 17% (5 of 30 patients) and 25% (11 of 44 patients), respectively [13, 17].

The use of intraoperative three-dimensional (3D) fluoroscopy has become increasingly popular. It allows for the evaluation of reduction quality, which cannot be achieved with plain X-rays, and ensures the proper positioning and length of each screw [18, 19]. The advantage of intraoperative 3D fluoroscopy was confirmed for complex DRFs by achieving optimal dorsal screw position and correcting malposition screw, and subsequently decreasing revision rates [20, 21].

Many studies explored intraoperative skyline view and intraoperative 3D fluoroscopy diagnostic values. Rausch et al. recommended skyline view rather than 3D fluoroscopy due to the technical, demanding, and time-consuming procedure [22]. However, Langerhuizen et al. study indicated that 3D fluoroscopy did not offer superior detection of dorsal screw penetration when compared to the skyline view [23]. Furthermore, Hammerle et al. demonstrated that intraoperative 3D fluoroscopy could potentially lower the risk of revision rate [24]. Due to the heterogeneity of current evidence, we aimed to explore and compare the diagnostic accuracy of the skyline view and 3D fluoroscopy in patients with unstable DRF, using postoperative CT as the reference standard in a cohort of patients with unstable intra-articular DRF.

Materials and methods

Patient characteristics

This is a retrospective cohort study. In this study, we enrolled the patients with unstable DRF treated surgically in the ICUC, short for Integrated Complete Unchanged Continued, registry database. The ICUC database prospectively collected clinical images of patients from five trauma centers, including four hospitals in Europe and one in Uruguay [25, 26]. The Strengthening the Reporting of Observational Studies in Epidemiology guidelines were followed entirely in this study [27]. The Institutional Review Board of a university-affiliated hospital approved this study to analyze the ICUC database. Inclusion criteria were: (1) patients with unstable intra-articular or dorsal comminuted DRF and (2) patients treated with VLP fixation. Exclusion criteria were patients under 18 years old and those for whom intraoperative skyline views, intraoperative 3D fluoroscopic scans, and postoperative CT scans were unavailable.

Intraoperative skyline view and 3D fluoroscopic scans

The skyline view was displayed as elaborated by Haug et al. [28]. The forearm is intraoperatively placed at 75° inclination to the table with the wrist hyperflexion (Fig. 1). This enabled surgeons to evaluate the dorsal cortex of the distal radius [29]. Intraoperative skyline views are shown in Fig. 2A. Intraoperative 3D fluoroscopy's coronal, axial, and sagittal views were collected to detect dorsal screw protrusion. The 2D and 3D fluoroscopic images were captured using the Vision RFD 3D system (Ziehm Imaging Inc., Nuremberg, Germany) (Fig. 2A–D). For assessment of dorsal screw protrusion, we defined screws that did not protrude the dorsal cortex, either falling short or just reaching the cortex, as "short," and those that protrude through the cortex as "through."

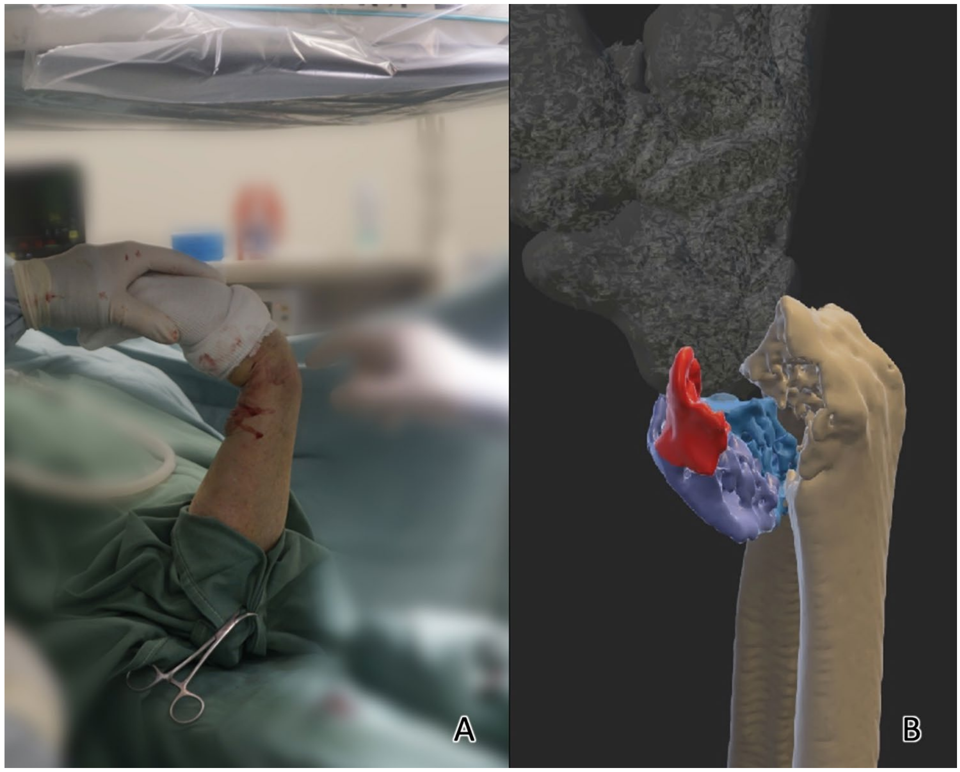

Fig. 1 Skyline view. Extreme wrist flexion (**A**) immediately after volar locking plating may pose a risk of construct failure, especially in volar shearing fractures (**B**)

3D fluoroscopic scans efficacy and radiation dose

The entire process takes approximately five minutes, from preparation to scan completion. During this period, the scan execution phase lasts approximately 40 seconds.

During the radiation exposure, both the patient and the anesthesiologist are protected by radiation protection shield, including thyroid shields, and each wore a dosimeter. According to the official manual from Ziehm Imaging Inc., the radiation dose for imaging the hand using a 16 cm phantom varies depending on the settings: with an attached anti-scatter grid and the adult dose program activated, the weighted CTDI is 1.97 mGy; with an attached anti-scatter grid and the low dose function activated, the weighted CTDI is 1.25 mGy; and with the anti-scatter grid removed and the low dose function activated, the weighted CTDI is 1.23 mGy.

Postoperative CT as the reference standard

Postoperative CT scans were collected as reference standards, including coronal, axial, and sagittal views (Fig. 2E-F). Two independent observers, C.-H. W. and W-C. L. evaluated dorsal screw protrusion. Discrepancies between their assessments were resolved by the senior author, A. A. F. Interrater reliability was analyzed using established criteria.

Statistical analysis

The Shapiro-Wilk and Shapiro-Francia tests were utilized to assess normality. Continuous variables with a normal distribution were expressed as standard deviation, while categorical variables were presented as numbers (percentages). The Kappa value was used as a quantitative measure to assess the level of agreement. The level of agreement corresponds to the value of Cohen Kappa was defined as follows: almost perfect (0.80–1.00), substantial (0.60–0.79), moderate (0.40–0.59), fair (0.21–0.39), slight (0–0.20) and no agreement (-0.10–0) [30]. Confidence intervals (CIs) were calculated by standard deviation. A one-sample, two-sided correlation test was conducted with a sample size of 84 and a significance level of 0.05. The power of 3D fluoroscopy compared to the Skyline view was computed based on these conditions. The sensitivity as well as specificity of the diagnostic performance compared to postoperative CT were based on the 25% prevalence of dorsal screw protrusion and were calculated using the DIAGT command in STATA 15.1 [31].

Results

Patient characteristics

A total of 21 patients met the inclusion criteria in the ICUC registry database (Fig. 3). The entire cohort of patients was prospectively enrolled from one of the ICUC trauma centers located in Uruguay. The demographic

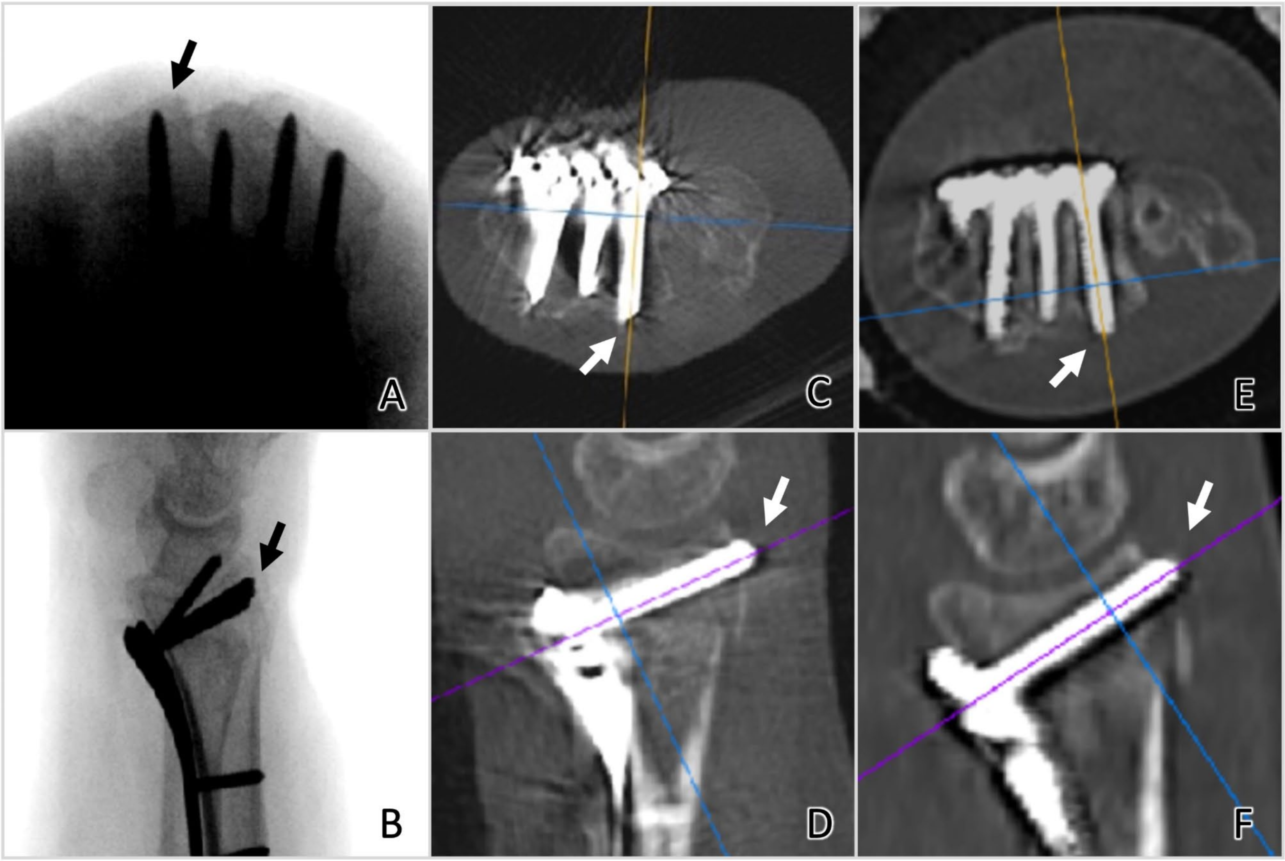

Fig. 2 Operative images. (**A**) Intraoperative 2D fluoroscopic skyline view showing no dorsal screw protrusion (black arrow). Note that the dorsal cortex overlaps with the distal carpal row, sometimes making it difficult to determine screw protrusion. (**B**): Intraoperative 2D fluoroscopic anatomical tilt lateral view showing no dorsal screw protrusion (black arrow). (**C**) Coronal view and (**D**) sagittal view of intraoperative 3D fluoroscopy displaying dorsal screw protrusion (white arrows), which is consistent with (**E**) coronal view and (**F**) sagittal view of postoperative CT scans

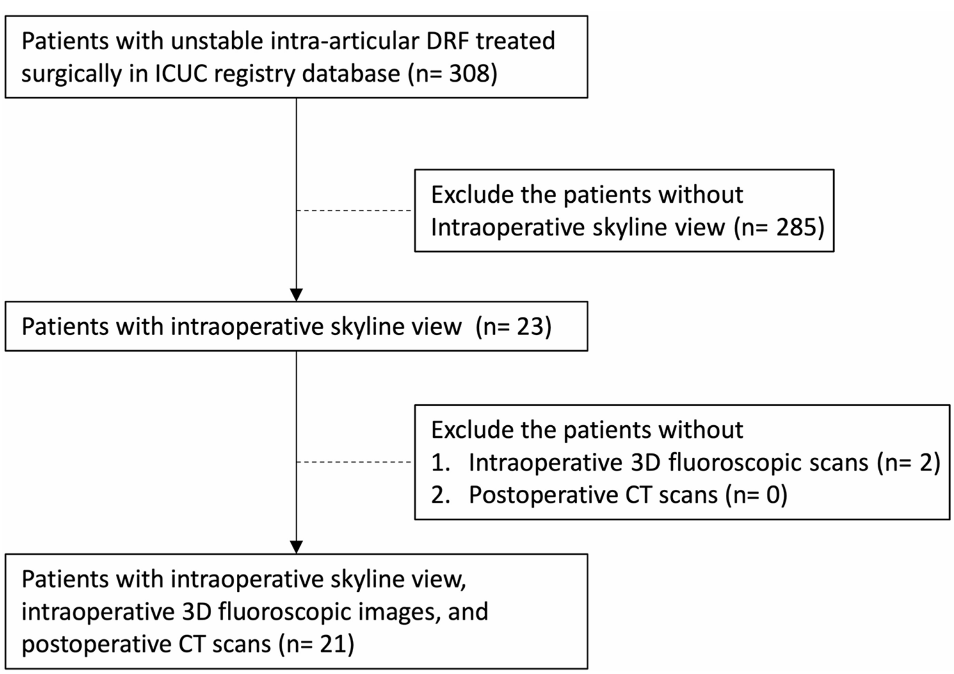

Fig. 3 Flowchart of patients in the study

Table 1 Patient characteristics

Variables	*N* = 21
Age (year), Mean (SD)	62.6 (16.8)
Sex	
Female, No. (%)	18 (85.7)
Male, No. (%)	3 (14.3)
Fractured wrist	
Left, No. (%)	13 (61.9)
Right, No. (%)	8 (38.1)
AO Classification, No. (%)	
2R3A3	9 (42.9)
2R3B3	2 (9.5)
2R3C2/2R3C3	2 (9.5) / 8 (30.1)
Dorsal Comminution, No. (%)	17 (81.0)

Table 2 Diagnostic performance of skyline views and 3D fluoroscopy in detecting Screw Protrusion through the dorsal cortex

Diagnostic performance characteristics	Skyline view	3D fluoroscopy
Sensitivity (95% CI)	72.2% (46.5–90.3)	81.8% (59.7–94.8)
Specificity (95% CI)	90.9% (81.3–96.6)	98.4% (91.3–100)
Negative predictive value (95% CI)	90.8% (82.3–95.4)	94.2% (87.0–97.5)
Positive predictive value (95% CI)	72.6% (54.0–85.7)	94.4% (70.6–99.2)

CI: confidence interval

characteristics and fracture patterns according to the AO classification are detailed in Table 1. The study included 18 women and 3 men, with a mean age of 62.6 ± 16.8 years. All patients underwent intraoperative anatomical AP and lateral tilt views, skyline views, and 3D fluoroscopic imaging. Among the enrolled cases, 15 (63.6%) were classified as complex DRF (AO type C). Additionally, 12 cases (57.1%) exhibited dorsal wall comminution. All clinical image galleries are provided in electronic supplementary material.

Interrater reliability

A total of 84 locking screws were evaluated. The interrater reliability results were evaluated with kappa values of 0.481 (95% CI: 0.297–0.652, $N = 84$) and 0.839 (95% CI: 0.703–0.975, $N = 84$) between skyline views and 3D fluoroscopy, based on postoperative CT scans as the ground truth standard. Skyline views were unable to detect 10 screws and identified 56 shorter screws and 18 screw penetrations, with moderate agreement. In contrast, 3D fluoroscopy identified 62 shorter screws and 22 screw penetrations, with almost perfect agreement.

Power analysis

When $ra = 0.839$ and $r_0 = 0.481$, a one-sample, two-sided correlation test with a significance level of 0.05 and sample number of 84 indicates that the estimated power is 1.000.

Diagnostic performance

The diagnostic performance characteristics were evaluated with sensitivity and specificity (Table 2). The sensitivity of intraoperative skyline views to detect penetrating screws were 72.2% (95% CI, 46.5–90.3) and 90.9% (95% CI, 81.3–96.6), respectively, with a negative predictive value (NPV) of 90.8% (95% CI, 82.3–95.4). Furthermore, the sensitivity and specificity of intraoperative skyline views to detect dorsal screws protrusion were 81.8% (95% CI, 59.7–94.8) and 98.4% (95% CI, 91.3–100), respectively, with a NPV of 94.2% (95% CI, 87.0–97.5).

Discussion

Based on our retrospective analysis from the ICUC database, the skyline views offer only moderate evaluation of dorsal screw protrusion in patients with unstable intra-articular DRF surgically treated in VLP fixation, whereas 3D fluoroscopy demonstrates nearly perfect agreement. Moreover, we highlighted that 3D fluoroscopy displayed better diagnostic values than skyline views for detecting screw penetration.

Jacob first proposed to visualize the dorsal cortex of the distal radius through a skyline view [32]. The detection of dorsal screw protrusion in a skyline view has been validated and recommended by many studies in the last decade [13, 15, 33–35]. Many studies have indicated that the skyline view is not sufficiently sensitive to detect all instances of screw tip protrusion. This is due to the complexity of the distal radius fracture and the volume of soft tissues in the forearm [36, 37]. It is not permissible to adjust the screw position based solely on the skyline view if it penetrates the radiocarpal joint. Surgeons typically need to combine the use of classic AP and lateral anatomical tilt views for a more comprehensive assessment of screw position. Consequently, the sensitivity of the skyline view can vary depending on several conditions.

Apart from the radiographic limitation, there's a concern about the position of the skyline view. Two skyline view techniques have been depicted: a supinated forearm with vertical placement and a pronated forearm with horizontal placement in fluoroscopy [14, 38]. The disadvantage of the former method is that the carpus can obscure the dorsal cortex of the radius. The latter approach often makes it difficult to ascertain whether the screw has penetrated the distal radioulnar joint. To get an ideal skyline view, full supination and flexion of the wrist are required for forced volar positioning [39]. The optimal inclination angle to the X-ray beam varies between

5° and 20°, depending on the geometric variations of each radius [40]. There is a potential for fracture displacement, particularly in volar shear fractures, typically caused by low-energy shearing forces [41]. The forced flexion position can exacerbate this condition, increasing the risk of construct failure.

Besides, appropriate fluoroscopic modality would determine the accuracy of the skyline view. Mini C-arm fluoroscopy offers a real-time assessment of the quality of fracture reduction in the wrist, so it is commonly used during DRF fixation [42–44]. However, ample space for a skyline view is required to position the entire arm within the operational range of the fluoroscopy unit. Given the limited space of the mini C-arm, surgeons must position the wrist in an extended supination posture. For optimal visualization of the screw position, using a large C-arm to capture the skyline view is recommended. Consequently, it is necessary to allocate sufficient space in the operating room to accommodate the large C-arm.

Intraoperative 3D fluoroscopy has become increasingly popular due to recent technological advances in 3D scanning capabilities, which are based on the platform of a large C-arm [45]. 3D fluoroscopy was considered adequate and similar to CT for imaging subtle bony structures [46]. Atesok et al. proposed that intraoperative 3D fluoroscopy for intra-articular fractures enabled surgeons to identify mal-reduction and implant malposition [47]. With the increasing utility of 3D fluoroscopy, many studies investigated the sensitivity of detection for screw protrusion to conventional scans, including ultrasound and 2D-fluoroscopy during intra-articular DRF fixation. To our best known, several studies revealed that 3D fluoroscopy was not superior to skyline view [10, 22, 23]. Among these studies, only Langerhuizen et al. showed the diagnostic values of dorsal screw protrusion between skyline view (sensitivity: 39% and specificity: 91%) and 3D fluoroscopy (sensitivity: 25% and specificity: 93%) [23]. Their reported sensitivity differs from our findings. A possible explanation for Langerhuizen et al.'s findings is that they evaluated the use of skyline view and 3D fluoroscopy on different distal radius cohorts. This made it difficult to control for variations in soft tissue volume in the forearm and the complexity of the dorsal wall fracture between groups. In contrast, our study examined a single cohort, using both 2D and 3D fluoroscopic views to detect screw protrusion. This approach allows for a more precise comparison of the detection accuracy between the two modalities.

The occupational issue between skyline view and 3D fluoroscopy was radiation exposure. To our knowledge, no previous studies investigated the radiation exposure between skyline view and 3D fluoroscopy. It is challenging to accurately quantify intraoperative radiation exposure among surgeons due to poor compliance with dosimeters [48]. Besides, careful wrist positioning is needed to ensure an optimal incident angle for the imaging source. This leads to cumulative radiation exposure for surgeons seeking optimal anatomical tilt and skyline views, thus increasing occupational radiation exposure. A surgeon or an assistant's hand is at the highest risk for exposure to a direct radiation beam to keep wrist hyperflexion for a skyline view [49]. In contrast, surgeons are away from the field during intraoperative scanning, making 3D fluoroscopy a valuable modality. Regarding occupational radiation exposure, most surgeons do not commonly use radiation-protective gloves [50]. From the perspective of occupational radiation exposure, further investigation into quantitative radiation studies on the hands is necessary.

Based on our analysis from the ICUC database and the perspectives mentioned above, the strength of our study was that if fluoroscopy with a 3D scanning function is feasible, an additional intraoperative 3D fluoroscopy could provide a better detection for screw's position whether there is a dorsal protrusion or intra-articular penetration into the radiocarpal or distal radioulnar joint, slightly increase the acceptable radiation exposure to patients, and decrease the cumulative radiation exposure to surgeons. We also highlighted that 3D fluoroscopy has better diagnostic values than skyline view in patients with unstable intra-articular DRF through VLP fixation.

There are several limitations to this study. First, only a few patients in the ICUC database met the inclusion criteria. However, the number of included patients exceeded the minimum required based on the power analysis for a one-sample proportion test. Second, the diagnostic performance characteristics were analyzed based on the Navas-Reyes et al. study [17], and the incidence of dorsal screw protrusion would be decreased with the progress and the development of intraoperative imaging devices [51]. Third, we did not assess the clinical outcome in this study. Further investigation of complications such as EPL irritation, tear or even rupture postoperatively during long term follow up is necessary to demonstrate the benefit of intra-operative 3D fluoroscopy. Our previous study evaluated the clinical outcome of the patients with DRF in the ICUC database through ICUC trauma score, a patient-related outcomes for patients to self-assess functional outcomes [26]. To sum up, further studies with larger cohorts and various fluoroscopy modalities are needed to validate our findings.

Conclusion

The accuracy of the skyline view is contingent upon the appropriate selection of the fluoroscopic modality, optimal wrist positioning, and precise alignment with the imaging source. While skyline views provide only moderate assessment of dorsal screw protrusion, 3D fluoroscopy achieves nearly perfect agreement in this evaluation. Given the high reliability and the potential to reduce cumulative radiation exposure, 3D fluoroscopy allows surgeons to maintain a safe distance from the field during scanning. This underscores 3D fluoroscopy as an invaluable intraoperative modality.

Abbreviations

CI	Confidence interval
CT	Computed tomography
DRF	Distal radius fracture
NPV	Negative predictive value
VLP	Volar locking plate
3D	Three-dimensional

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05573-x.

Supplementary Material 1

Author contributions

Conceptualization: all authors; Methodology: all authors; Formal analysis and investigation: C.-H. W., W-C. L. and L.C.; Original writing draft preparation: C.-H. W. and W-C. L.; Draft review and editing: all authors; Resources: A.F.; Supervision: JB.J., P.R. and A.F.

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Data availability

All relevant data and intraoperative images are provided as supplementary materials accompanying this manuscript.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of a university-affiliated hospital (KMUHIRB-E(I)-20230185) to analyze the ICUC registry database.

Consent for publication

There is no information (names, initials, hospital identification numbers or photographs) in the submitted manuscript that can be used to identify patients.

Competing interests

The authors declare no competing interests.

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