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Alternative Technique to Reduce Radiation Exposure during Locked Plate Fixation of Distal Radius Fracture; the Plummet as a Targeting Device

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Purpose: Radiation exposure from intraoperative fluoroscopy is routinely encountered in orthopedic procedures, especially during distal radius fracture fixation. Prolonged exposure to high-dose radiation is a known risk factor for genetic mutations. This study presents a simple, alternative mechanical targeting device using a plummet that functions as a laser aimer.

Methods: A prospective randomized controlled trial was conducted at a single institution involving 42 consecutive patients who underwent locked plate fixation for distal radius fractures and were randomized into two groups. One group underwent fluoroscopic imaging using a plummet as the aiming device, whereas the other group underwent imaging without an aimer. The radiation exposure time, dose, and fluoroscopy accuracy were recorded and analyzed.

Results: A total of 42 patients were enrolled, with 21 assigned to the Plummet group and 21 to the Control group. Demographic data and fracture patterns were comparable between the groups. Compared to the Control group, the Plummet group required significantly fewer fluoroscopic images (8.38 vs. 21.86) and demonstrated a higher accuracy of fluoroscopy (99.21% vs. 67.53%). Radiation exposure was also lower in the Plummet group (3.78 vs. 9.98 μSv), with a shorter ionizing radiation exposure time (0.05 vs. 0.13 min). Operative time was also reduced in the Plummet group (51.52 vs. 60.81 min).

Conclusions: Compared to the conventional method, the use of a plummet as an aiming device significantly reduced the number of fluoroscopic images, radiation exposure, and operative time, while improving the accuracy of fluoroscopy.

Keywords: Radiation exposure, Intraoperative fluoroscopy, Distal radius fracture, Aiming devices

Although it has been known for many decades, intraoperative fluoroscopy has become routine in many orthopedic procedures. Anatomical volar locking plate fixation of unstable distal radius fractures requires intraoperative fluoroscopy. It provides real-time imaging to assess the quality of fracture reduction, implant positioning, and proper screw length and direction. However, its use results in increased exposure to both direct and scattered ionizing radiation (X-radiation) by orthopedic surgeons, patients, and surgical teams, which presents serious safety concerns and occupational hazards. The effect of ionizing radiation exposure has been well-documented in

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the literature. It increases the risk of cellular damage, radiation-induced cataracts, infertility, papillary thyroid carcinoma, and potential genetic effects in future generations. There is no known safe dose of ionizing radiation.[1,2,3-8]

The use of practical radiation protection (lead-equivalent goggles, thyroid collar, and lead apron), the ALARA principle (as low as reasonably achievable)[1-4,8]and laser-aiming devices can reduce radiation exposure[10], a laser-aiming device can significantly reduce the ionizing radiation exposure time and dose by increasing the accuracy of intraoperative fluoroscopic images[10,11-13]. However, laser-aimed devices are not always available in orthopedic operating rooms. Consequently, the purpose of this study was to use a plummet as a simple mechanical targeting device that functions similarly to a laser aimer in identifying the center of the image intensifier and placed over the desired area before shooting the ionizing radiation beam during open reduction and internal fixation with anatomical volar locking plate fixation of unstable distal radius fractures and to compares the ionizing radiation exposure time, radiation dose, and accuracy of intraoperative fluoroscopy with and without the use of the plummet as a targeting device.

PATIENTS AND METHODS

This prospective randomized controlled trial was approved by the Institutional Review Board (IRB approval: KPEC No.32/2568) and was registered in Thai Clinical Trials Registry: TCTR20251229001. All patients provided written informed consent prior to participation. The authors declare that they worked independently and did not receive assistance or support from others during the study.

The sample size was calculated before the study using standard statistical methods. A Type I error (α) of 5% and a Type II error (β) of 20% were considered, with the significance level set at $p < 0.05$. Based on these parameters, the minimum required sample size was 38 participants[14-18].

All consecutive patients diagnosed with unstable distal radius fractures at Kumpawapi Hospital between June and September 2025 were included in this study. The exclusion criteria were as follow: 1. Age under 18 years, 2. refusal to participate, and 3. Unfit for surgery or anesthesia. A total of 42 consecutive patients underwent open reduction and internal fixation with anatomical volar locking plate fixation performed by a single orthopedic surgeon (the author). Patients were allocated into two groups using a quasi-randomized approach based on their date of birth (odd or even): one group (Plummet group) underwent intraoperative fluoroscopic imaging with a plummet weighing 100 g, made of polished sterilizable steel, obtained commercially from a general hardware supplier, and used as a targeting device. The other group (Control group) underwent intraoperative fluoroscopic imaging without an aiming device. A mobile C-arm unit (Ziehm Solo, Germany), was used for all intraoperative fluoroscopy in this study, which automatically sets its mA and kV values according to the soft tissue thickness of the patients. The setting of intraoperative fluoroscopy using the plummet as a targeting device ensured optimal image quality and minimized the setup variability. The intensifying screen was fitted with custom-designed, sterile, protective drapes. These drapes were produced through a meticulous tailoring process to achieve a precise custom fit over the screen housing while ensuring no obstruction of the fluoroscopic view. The objective of this setup was to achieve accurate alignment of the central axis of the ionizing radiation beam, the hanging point of the plummet and the manufacturer-marked center of the intensifying screen. This was accomplished by locating the hanging point of the plummet at the geometric center of the screen, which was circular. For each unit used, we confirmed that the hanging point corresponded exactly to the industry-designated center of the intensifying screen. Throughout the procedure, the intensifying screen was positioned above the radiation source (to reduce scattered radiation), perpendicular to the operating arm's table, and parallel to the ground. This accurately aligned the hanging point of the plummet with the central axis of the ionizing radiation beam *(Figure 1)*. A plummet is a simple mechanical targeting device that functions similarly to a laser aimer to identify the center of the image intensifier. It is placed over the desired anatomical site (approximately 5 cm) by hanging with a 2-0 silk suture at the hanging point. It must be moved away from the imaging filed before shooting each single shot of the ionizing radiation beam while operating, as it is not a radiolucent plummet material. Measurements of mA, kV, ionizing radiation exposure time, radiation dose, and accuracy of intraoperative fluoroscopy were recorded on the display of the fluoroscope which was automatically generated by the same radiologic technician in a case record form that could not identify participants.

Fig. 1 Fluoroscopic setting in the Plummet group.

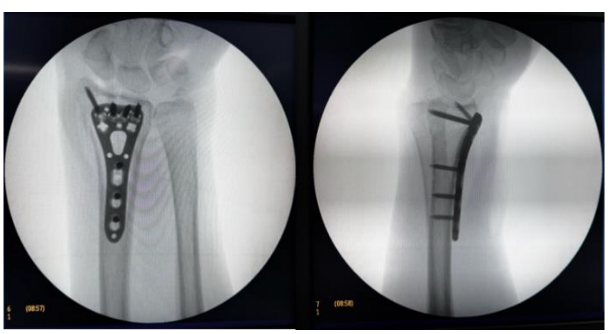

Fig. 2 Example of an accurate intraoperative fluoroscopic image.

Following the intraoperative fluoroscopic setup in both groups, standard anteroposterior (AP), lateral, oblique, and/or tangential views were obtained by adjusting the patient's wrist position. An accurate image was defined as one that clearly showed the bony structure, screw, implant, or their relationship without requiring repeat image *(Figure 2)*. An inaccurate image failed to provide complete diagnostic information and required a repeat fluoroscopic image until accuracy was achieved. In this study, we focused on the center of the intraoperative fluoroscopy image if a repeat image was required because the position of the patient's wrist was not true AP or lateral but still demonstrated all necessary anatomical details when properly aligned (centering accuracy); it was classified as an accurate image.

Statistical analysis for descriptive statistics were used to present normally distributed data as mean ± standard deviation (SD). Chi-square and Fisher's exact tests for inferential statistics were used to compare categorical variables. The independent t-test was used to compare the means of two independent groups, and was applied to test for significant difference in ionizing radiation exposure time, radiation dose, and accuracy of intraoperative fluoroscopy between two groups and a p-value < 0.05 was determined to be statistically significant.

RESULTS

General Characteristics

A total of 42 patients were included in this study, with 21 patients were assigned to the Plummet group and the remaining 21 to the Control group. As shown in *Table 1*, the two groups were comparable in terms of demographic characteristics. Both groups consisted of 9 males (42.86%) and 12 females (57.14%). The mean age was 56.10 years (range, 38–75 years) in the Plummet group and 54.86 years (range, 19–83 years) in the Control group, with no significant difference between the groups ($p = 0.792$).

Fracture Classification

The distribution of unstable distal radius fractures according to the AO/OTA classification is shown in *Table 2*. In the Plummet group, 9 patients (42.86%) were classified as AO/OTA 23-B3, representing partial articular fractures with a volar rim fragment; 9 patients (42.86%) were classified as AO/OTA 23-C1, defined as complete articular fractures with simple articular and simple metaphyseal fragments; and 3 patients (14.28%) were classified as AO/OTA 23-C2, corresponding to complete articular fractures with simple articular involvement and metaphyseal comminution. In the Control group, 5 patients (23.81%) were classified as AO/OTA 23-B3, 12 (57.14%) as AO/OTA 23-C1, and 4 (19.05%) as AO/OTA 23-C2. There were no statistically significant differences in fracture classification between the two groups (p = 0.190, 0.355, and 1.000, respectively).

Statistical Analysis of Fluoroscopic Imaging and Radiation Outputs

Table 3 summarizes the intraoperative imaging and radiation outputs which they were automatically generated by the C-arm. No significant differences were found in the mean X-ray tube voltage (50.20 ± 1.81 kV vs. 50.63 ± 1.24 kV, p = 0.372) or radiation output (2.71 ± 0.31 mA vs. 2.81 ± 0.40 mA, p = 0.362) between the Plummet and Control groups.

However, the Plummet group required significantly fewer fluoroscopic images (8.38 ± 2.73 vs. 21.86 ± 7.67, p < 0.001) and established a higher accuracy of fluoroscopy (99.21% ± 3.64 vs. 67.53% ± 8.39, p < 0.001). The number of inaccurate images was markedly reduced in the Plummet group (0.05 ± 0.22 vs. 6.81 ± 2.20, p < 0.001).

Radiation exposure dose was also substantially lower in the Plummet group, with a mean total ionizing radiation dose of 3.78 ± 1.75 μSv compared with 9.98 ± 4.12 μSv in the Control group (p < 0.001), and a shorter total radiation exposure time (0.05 ± 0.02 min vs. 0.13 ± 0.04 min, p < 0.001). Furthermore, operative time was significantly shorter in the Plummet group than in the Control group (51.52 ± 12.20 min vs. 60.81 ± 15.95 min, p = 0.040).

Post-Operative Follow-Up of Wound Infection at 2, 4, and 6 Weeks

As shown in Table 4, no cases of wound infection were observed in either group at any follow-up interval (2, 4, or 6 weeks). As both groups had zero events, Fisher's exact test yielded P = 1.000 at all time points, indicating no significant difference in postoperative wound infection between groups.

Table 1 General characteristics of the patients in the study. (n=42)

	Plummet group (n=21)	**Control group (n=21)**	***p***
Male	9 (42.86%)	9 (42.86%)	1.000[a]
Female	12 (57.14%)	12 (57.14%)	1.000[a]
Mean age; year (SD)	56.10 (10.06)	54.86 (18.82)	0.792[a]
[min-max]	[38-75]	[19-83]	

p-value was calculated using [a]chi-square test

Table 2 Diagnosis by AO/OTA classification.

	Plummet group (n=21)	**Control group (n=21)**	***p***
AO/OTA 23-B3	9 (42.86%)	5 (23.81%)	0.190[a]
AO/OTA 23-C1	9 (42.86%)	12 (57.14%)	0.355[a]
AO/OTA 23-C2	3 (14.28%)	4 (19.05%)	1.000[b]

p-value was calculated using [a]chi-square test and [b]Fisher's exact test

Table 3 Statistical analysis of fluoroscopic imaging and radiation outputs.

	Mean Plummet group (SD)	Mean Control group (SD)	95% Confidence Interval of the Difference	*p*
X-ray tube voltage average; kV [min-max]	50.20 (1.81) [46.71-52.38]	50.63 (1.24) [45.48-53.43]	-1.40 - 0.54	0.372
Radiation output average; mA [min-max]	2.71 (0.31) [2.22-3.19]	2.81 (0.40) [2.08-3.39]	-0.33 - 0.12	0.362
Total number of fluoroscopic images [min-max]	8.38 (2.73) [6-17]	21.86 (7.67) [11-38]	-17.07 - -9.89	<0.001*[c]
Accurate images	8.33 (2.78)	15.05 (6.30)	-9.75 - -3.68	<0.001*[c]
Inaccurate images	0.05 (0.22)	6.81 (2.20)	-7.74 - -5.78	<0.001*[c]
Accuracy of fluoroscopy**; %	99.21 (3.64)	67.53 (8.39)	27.64 - 35.71	<0.001*[c]
Total dose of ionizing radiation; µSv	3.78 (1.75)	9.98 (4.12)	-8.17 - -4.23	<0.001*[c]
Total exposure time; min	0.05 (0.02)	0.13 (0.04)	- 0.10 - 0.06	<0.001*[c]
Operative time; min	51.52 (12.20)	60.81 (15.95)	-18.14 - -0.43	0.040*[c]

p-value was calculated using an [c]independent t-test
**Accuracy of fluoroscopy (%) = (accurate images/ total number of fluoroscopic images) x 100

Table 4 Postoperative follow-up of surgical wound infection at 2, 4, and 6 weeks.

	Plummet group (n=21)	Control group (n=21)	*p*
2 weeks	0	0	1.000[b]
4 weeks	0	0	1.000[b]
6 weeks	0	0	1.000[b]

p-value were calculated using [b]Fisher's exact test

DISCUSSION

For all ionizing radiation exposures, the exposure dose should be maintained at the minimum possible level during orthopedic surgery. To achieve this, the ALARA optimization rules (as low as reasonably achievable) were introduced. The goal of this principle is not to zero the radiation hazards but to lower the risks to an acceptable range that does not known the safe dose(1-4,8,9). In the present study, we demonstrated that the use of a plummet as a simple mechanical aiming device during open reduction and volar locking plate fixation of unstable distal radius fractures resulted in a significant reductions in radiation exposure. Specifically, the plummet reduced the total number of fluoroscopic images by 61.67%, the ionizing radiation dose by 62.12%, the radiation exposure time by 61.54%, and operative time by 15.28%, while increasing the imaging accuracy to approximately 100%. These findings highlight the potential of this low-cost, widely applicable technique for improving surgical safety and efficiency.

The substantial reduction in intraoperative fluoroscopic images and radiation exposure observed in this study is consistent with reports on laser-aiming devices, which have been shown to improve the accuracy of fluoroscopic images and reduce screening time in orthopedic procedures, such as dynamic hip screw fixation for extraarticular fractures of the proximal femur and foot and ankle surgery(10-13). However, unlike laser devices, which may be expensive or unavailable at many institutions, this plummet offers a practical and inexpensive alternative. This expands access to radiation-sparing technology, especially in resource-limited healthcare settings.

Radiation exposure during orthopedic surgery is a well-recognized occupational hazard for both patients and surgical teams[1-4,8-10]. The mean exposure dose in the Plummet group (3.78 μSv) was markedly lower than that in the Control group (9.98 μSv), reinforcing the importance of adopting measures that align with the ALARA principle (as low as reasonably achievable). Importantly, reduced fluoroscopic use is also correlated with shorter operative times, suggesting that the plummet not only enhances safety but may also improve operating room efficiency[5,6,7].

Another key finding was the improved accuracy of intraoperative fluoroscopy (99.21% vs. 67.53%). Accurate imaging reduces the need for repeated exposures, thereby limiting cumulative radiation risk and improving intraoperative workflow. These results support the role of mechanical or optical systems in enhancing intraoperative imaging quality[11,12,13].

An additional important finding of this study was the absence of postoperative wound infections in either group at 2, 4, or 6 weeks after surgery. Although the sample size was limited, the complete lack of infectious complications suggests that plummet use does not introduce any additional risk to soft-tissue healing or wound integrity. Theoretical concerns include possible contamination from repeated device manipulations or workflow interruptions; however, these were not observed in the present study. Similar outcomes between the Plummet and Control groups ($p = 1.000$ for all time points) further support the safety of this technique. These findings suggest that the radiation-sparing benefits of plummet are not offset by increased postoperative morbidity. Future studies with larger cohorts may help determine whether this equivalence in infection risk persists across broader patient populations and more complex fracture patterns.

This study had several strengths, including its randomized controlled trial design, standardized surgical technique performed by a single surgeon (the author), and objective measurement of fluoroscopic parameters automatically directed from the C-arm system. However, this study had some limitations. First, group allocation based on odd or even birth dates represents a quasi-randomized method rather than true randomization. Although the baseline characteristics were comparable, the predictable assignment may have introduced selection bias and affected internal validity. Future studies should adopt rigorous randomization techniques, such as sealed opaque envelopes or computer-generated block randomization. Second, the study was conducted at a single institution with a relatively small sample size, which may limit the generalizability of our findings. Third, the plummet must be manually removed before each fluoroscopic exposure, introducing a minor workflow interruption. In practice, the interruption was small but measurable, and in one instance (case 5 in the Plummet group), failure to remove the plummet resulted in a single, inaccurate image. Although this did not materially diminish the overall time savings observed, surgeons adopting this technique should be aware that consistent, deliberate removal of the device is necessary to prevent similar errors. Design refinements, such as retractable or detachable mechanisms, could mitigate this in future iterations. Fourth, only distal radius fracture fixation was studied, and further research is needed to evaluate the applicability of this surgical technique to other orthopedic procedures. Finally, the plummet function is dependent on gravitational alignment. It can only be used when the C-arm is positioned perpendicular to the floor, limiting its applicability to true lateral, oblique, or angled views, which are often essential for distal radius fixation. In this study, standard anteroposterior (AP), lateral, oblique, and/or tangential views were obtained by adjusting only the wrist position, allowing the C-arm to remain in a gravity-aligned orientation that was compatible with the plummet design. This constraint should be emphasized by surgeons when considering the adoption of this technique, as it restricts its use to specific imaging orientations [10]. Despite these limitations, our findings suggest that a plummet may serve as a safe, effective, and low-cost alternative to laser-aiming devices for reducing radiation hazards during orthopedic surgery.

CONCLUSIONS

The use of a plummet as a mechanical targeting device during open reduction and volar locking plate fixation of unstable distal radius fractures significantly reduced the number of fluoroscopic images, radiation dose, and exposure time by more than 60%, while improving imaging accuracy by almost 100% and shortening operative time. Compared to conventional methods, this technique offers a safe, practical, and inexpensive alternative that aligns with radiation safety principles (the ALARA principle) and may be particularly valuable in settings where laser-aiming devices are unavailable. Further multicenter studies with larger sample sizes are warranted to confirm these results and explore their wide application in orthopedic procedures.

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