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Original Research

# Volar Locking Plate Fixation for Distal Radius Fractures by Intraoperative Computed Tomographic–Guided Navigation

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*Purpose:* Unstable distal radius intra-articular fractures require restoration of alignment. Exact fixation of intra-articular fragments is ideal. Here, we employed intraoperative computed tomography (CT) navigation to insert screws accurately in the intra-articular dorsal fragments during treatment with a volar locking plate for distal radius intra-articular fractures. The main purposes of this study were to evaluate the accuracy of this procedure and the postoperative stability of the articular fragments through CT findings, as well as to assess clinical outcomes.
*Methods:* This study included 26 patients with distal radius fractures, who were treated with a volar locking plate using intraoperative CT navigation with a minimum follow-up of 12 months. Mean patient age was 63 years and mean follow-up was 16 months. We examined the position of the inserted distal screws and articular displacement on preoperative, intraoperative, and post–bone union CT images. The 3 distal ulnar screw positions that influence the stability of the dorsoulnar articular fragment were evaluated. The Mayo wrist score and Disabilities of the Arm, Shoulder, and Hand score were also clinically evaluated.
*Results:* Computed tomography evaluation revealed that the distal locking screws were appropriately inserted at the subchondral position, with sufficient length to stabilize the dorsal fragments, and reduction and stability of the articular fragment were acceptable. At the final follow-up, mean Mayo wrist score was 90.8 and mean Disabilities of the Arm, Shoulder, and Hand score was 9.6.
*Conclusions:* Intraoperative CT navigation was successfully used for volar locking plate fixation of intra-articular distal radius fractures. Computed tomography evaluation revealed that the screws were precisely inserted for articular fragments and bone union was achieved, maintaining good intra-articular alignment. The findings demonstrate the accuracy of volar locking plate fixation assisted by intraoperative CT navigation and the good clinical outcomes of this procedure.
*Type of study/level of evidence:* Therapeutic IV.



The accurate reduction and secure fixation of articular fragments are ideal for the repair of unstable intra-articular distal radius fractures. At present, volar locking plate fixation for distal radius fractures is the most common treatment of such fractures. During volar locking plate fixation, accurate screw insertion is important to maintain the reduction of articular fragments.[1] Recently, computed tomography (CT)-guided navigation for spinal surgery, knee arthroplasty, and hip arthroplasty has been validated.[2–4] The main purpose of CT-guided navigation in orthopedic surgery is to install implants accurately. To pursue the accuracy of the fracture treatment, preoperative planning using a 3-dimensional CT model has been investigated and has made progress.[5–7] Intraoperative CT navigation allows intraoperative planning immediately after fracture reduction instead of using it for preoperative planning before fracture reduction. For spinal surgery, CT-guided navigation is reportedly useful for the accurate insertion of pedicle screws.[2,8–10] The basic concept of CT-guided navigation is the same as that for fracture repair, although anatomic fracture reduction before screw insertion is required. Previous studies reported the accuracy of CT-guided navigation for sacroiliac screw insertion to repair pelvic ring fractures.[11,12] Regarding intra-

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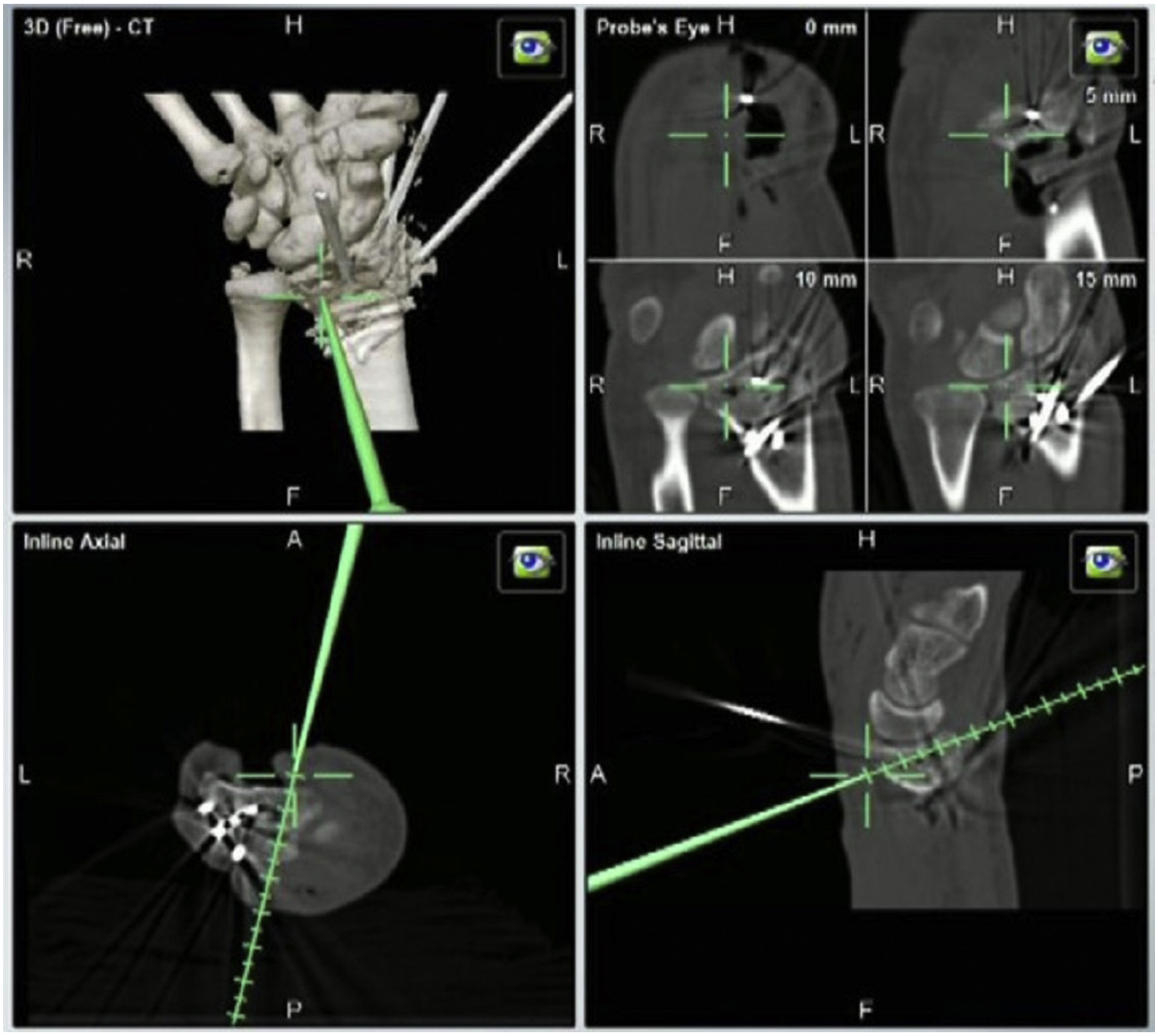


**Figure 1.** Navigation screen.

articular distal radius fractures, it is difficult to evaluate articular displacement and screw position precisely with intraoperative fluoroscopy; CT evaluation is more reliable.[13] In our institute, intraoperative CT-guided navigation has been used to insert screws accurately to secure articular fragments for the repair of intra-articular distal radius fractures.[14] We hypothesized that using CT navigation would allow accurate screw insertion, which would potentially improve outcomes. The purpose of the current study was to determine the efficacy of intraoperative CT navigation in treating intra-articular distal radius fractures. To evaluate the efficacy of intraoperative CT navigation, we assessed the accuracy of screw placement for the articular fragments and the postoperative stability of these fragments using intraoperative and post–bone union CT as the primary outcomes.

## Materials and Methods

Our institutional review board approved this retrospective study. From November 2015 to June 2018, volar locking plate (HYBRIX, Mizuho, Tokyo, Japan) fixation using intraoperative CT (SOMATOM Definition AS OPEN, Siemens, Erlangen, Germany)-guided navigation (Kolibri, Brainlab, Feldkirchen, Germany) was performed for the repair of 28 intra-articular distal radius fractures. The surgery was performed under general anesthesia in all cases. The CT scan, which is a mobile gantry type and 64-slice multi-detector CT, is equipped in the operating room. We selected CT navigation surgery when the operating room equipped with CT was available. This study included 26 fractures with a minimum follow-up of 12 months; 2 fractures were excluded because the follow-up period was less than 12 months. Mean patient age was 63 ± 15 years; mean follow-up duration was 16 ± 4 months. According to the AO classification, 3 cases were classified as C1, 8 as C2, and 15 as C3. Mean surgical time was 158 ± 32 minutes. The HYBRIX plate has a unique locking system in which the distal first row of the plate has a monoaxial locking system and the distal second row has a poly-axial locking system. This plate has an anatomical design; the distal end of the plate does not extend beyond the watershed region of the distal radius.

In brief, the CT-guided navigation procedure was performed as follows. (1) The fracture site was exposed through the trans-flexor

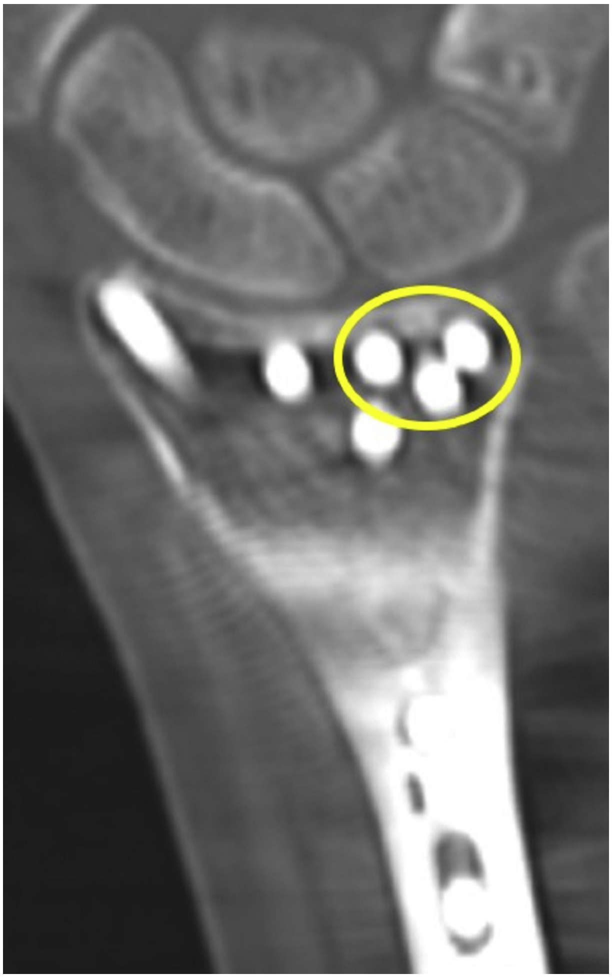

**Figure 2.** Three distal ulnar screws (yellow circle; 2 screws of the first row and one of the second row).

**Table 1**
Mean Minimum Distance Between Screw and Articular Surface

| Joint | Screw Position | During Surgery, mm | After Bone Union, mm | *P* Value* |
|---|---|---|---|---|
| Radiocarpal | First row (1) | 1.2 (±0.6) | 0.9 (±0.8) | .02 |
| | First row (2) | 1.7 (±0.9) | 1.4 (±0.8) | .06 |
| | Second row | 1.6 (±0.7) | 1.3 (±0.9) | .01 |
| Distal radioulnar | First row (1) | 1.5 (±0.7) | 1.3 (±0.7) | .03 |

* Wilcoxon signed-rank test.

**Table 2**
Mean Minimum Distance Between Screw Tips and Dorsal Cortex

| Screw Position | During Surgery, mm | After Bone Union, mm | *P* Value* |
|---|---|---|---|
| First row (1) | 1.1 (±1.0) | 1.0 (±1.1) | .10 |
| First row (2) | 0.9 (±1.0) | 0.7 (±1.0) | .02 |
| Second row | 0.6 (±1.1) | 0.3 (±1.3) | .02 |

* Wilcoxon signed-rank test.

**Table 3**
Radiographic Parameters

| | Immediately After Surgery | After Bone Union | *P* Value* |
|---|---|---|---|
| UV | +0.2 (±1.1) mm | +0.6 (±1.3) mm | .02 |
| VT | 10.8° (±3.3°) | 10.1° (±4.3°) | .07 |
| RI | 22.2° (±2.4°) | 21.7° (±2.5°) | .10 |

* Wilcoxon signed-rank test.

carpi radialis approach and the fracture was reduced fluoroscopically. Then, percutaneous temporary pinning was performed. A referential array was installed on the radial diaphysis. (2) Computed tomography scanning was performed to confirm a reduction of the fracture. (3) The CT data were registered with the navigation system. (4) An infrared camera was used to image the positional relationship of the referential array and pointer or drill guide. The display on the navigation screen indicates the position and direction of the pointer or drill guide (Fig. 1). (5) The position, direction, and length of the inserted screws were predicted. We planned to insert the distal screws near the articular surface and dorsal cortex. Importantly, an accurate prediction of the first row monoaxial screw position leads to an accurate prediction of the plate position. (6) Distal screws were inserted before the proximal screws. (7) Finally, second CT scans were obtained to confirm the status of fracture reduction and the locations of the plate and screws.

Articular displacement and the positions of the inserted distal screws were evaluated on CT images. We calculated the gap and the stepoff, as indices of articular displacement, on preoperative, intraoperative and post–bone union CT images. The displacement adopted was the maximum value on the CT sagittal and coronal plane images. Mean minimum distances between the screw and articular surface of the radiocarpal and distal radioulnar joints, and between the screw tips and the dorsal cortex were calculated on intraoperative and post–bone union CT images. Three distal ulnar screw positions that influenced the stability of the dorsoulnar articular fragment were evaluated (Fig. 2). The ulnar variance (UV), volar tilt (VT), and radial inclination (RI) were calculated with the use of radiographs before and after surgery and at the final follow-up examination. We evaluated pain, grip strength, range of motion, Mayo wrist score, and Disabilities of the Arm, Shoulder, and Hand (DASH) score. Statistical analysis was performed with the Wilcoxon signed-rank test; $P < .05$ was considered as significant. We also analyzed CT radiation exposure, and examined complications of infection, complex regional pain syndrome (CRPS), neurovascular events, tendon rupture, screw penetration into the joints, screw protrusion of the dorsal cortex, and postoperative displacement. According to the American Academy of Orthopaedic Surgeons Clinical Practice Guideline,[15] operative fixation of distal radius fractures is recommended with radial shortening of greater than 3 mm, dorsal tilt of greater than 10°, or intra-articular displacement or stepoff of greater than 2 mm. These parameters are considered to be an unacceptable reduction. Therefore, in this study, postoperative displacement was defined as loss of reduction resulting in unacceptable reduction.

As an indicator of CT radiation exposure, the dose-length products (mGy · cm) of preoperative, intraoperative, and post–bone union CT were recorded.

As a control group, we used 122 intra-articular AO-type C fractures treated by conventional fluoroscopic volar locking plate fixation during the same period. Mean surgical time in this group was 97 ± 22 minutes. Among these cases, 97 were available for postoperative CT and 25 were not. Of the 122 cases, 39 were not followed up for more than 12 months. Because of the low follow-up rate in the control group, only complications in the group were compared in this study.

**Figure 3.** Initial radiographic and CT images.

## Results

### *Computed tomography evaluation*

Mean gap and stepoff were 3.1 ± 1.6 and 1.8 ± 1.1 mm before surgery, 1.1 ± 0.6 and 0.4 ± 0.6 mm during surgery, and 0.5 ± 0.7 and 0.4 ± 0.5 mm after union, respectively. The acceptable reduction in the articular displacement was maintained until bone union. Mean distances between the screws and the articular surface of the radiocarpal joint from the ulnar side were 1.2 ± 0.6, 1.6 ± 0.7, and 1.7 ± 0.9 mm during surgery, and 0.9 ± 0.8, 1.3 ± 0.9, and 1.4 ± 0.8 mm after union (Table 1). Mean distances between the screw tips and the dorsal cortex from the ulnar side were 1.1 ± 1.0, 0.6 ± 1.1, and 0.9 ± 1.0 mm during surgery, and 1.0 ± 1.1, 0.3 ± 1.3, and 0.7 ± 1.0 mm after union (Table 2). All 78 evaluated screws were inserted less than 3 mm from the articular surface and less than 3 mm from the dorsal cortex. The locking screws were appropriately inserted at the subchondral positions and had sufficient length to stabilize the dorsal fragments. No screw penetrated the radiocarpal or distal radioulnar joints, and all screws reached near the dorsal cortex.

### *Plain radiographic evaluation*

Preoperative mean UV, VT, and RI were 3.2 ± 2.4 mm, −15.2° ± 17.4°, and 14.1° ± 6.0°, respectively. Immediately after surgery and at the final follow-up examination, mean UV was 0.2 ± 1.1 and 0.6 ± 1.3 mm, mean VT was 10.8° ± 3.3° and 10.1° ± 4.3°, and mean RI was 22.2° ± 2.4° and 21.7° ± 2.5°, respectively (Table 3). Correction loss was minimum and the stability of the fractures was maintained.

### *Clinical evaluation*

At the final follow-up, all 26 wrists had no pain or just mild pain. Mean visual analog scale score for pain (range, 0–100) was 4.8 ± 8.8. Mean grip strength was 22.5 ± 12.6 kg on the injured side and 24.7 ± 12.7 kg on the uninjured side. Mean wrist extension was 76.3° ± 6.3°, flexion was 68.1° ± 8.9°, pronation was 83.3° ± 3.7°, and supination was 87.7° ± 3.7° on the injured side, whereas mean extension was 78.7° ± 4.9°, flexion was 73.0° ± 7.3°, pronation was 84.4° ± 2.5°, and supination was 89.0° ± 4.2° on the uninjured side. Mean Mayo wrist score was 90.8 ± 6.3 points (excellent = 17 and good = 9) and the DASH score was 9.6 ± 16.2 points.

### *Complications*

Among 26 cases using CT navigation procedure, there was no infection, CRPS, flexor or extensor tendon rupture, neurovascular injury, screw penetration into the joints, prominent dorsal screw protrusion, or postoperative displacement during the follow-up periods. In contrast, among 122 cases treated under fluoroscopy, there was one infection, one CRPS, 2 flexor tendon ruptures, 2 extensor tendon ruptures, 10 cases of intra-articular screw penetration, 2 prominent dorsal screw protrusions requiring implant removal, and 10 cases of postoperative displacement. Among 10 postoperative displacements, 7 cases were related to improper screw insertion and plate position.

**Figure 4.** Intraoperative CT images.

*Computed tomography radiation exposure*

Mean dose-length products of preoperative, intraoperative, and post–bone union CT were 128.5 (±97.6), 84.7 (±36.4), and 124.4 (±62.8) mGy · cm, respectively. The intraoperative CT radiation dose was lower than the preoperative CT and post–bone union CT dose.

*Case presentation*

The patient was a 71-year-old woman who presented with an intra-articular distal radius fracture (AO classification of C3) (Fig. 3). Volar locking plate fixation was performed with CT-guided navigation. Intraoperative CT images after plate fixation indicated a good dorsoulnar fragment reduction and appropriate screw insertion (Fig. 4). The intra-articular fragments maintained good reduction and achieved bone union (Fig. 5). This patient reported no complications such as tendon rupture. The Mayo wrist score was excellent (90 points) and the DASH score was 4.6 points at the final follow-up examination.

## Discussion

The importance of supporting the subchondral bone under the articular surface with distal locking screws in volar locking plate fixation to repair distal radius fractures was previously reported.[16] Drobetz et al[17] reported that radial shortening was significantly greater when the distal screws were placed at least 4 mm proximal to the articular surface, and the distal screw should be positioned close to the joint line to prevent postoperative displacement.[1] Intra-articular screw penetration may occur if the monoaxial locking plate is placed distal to the optimal position. In such cases, shorter screws are preferable to longer screws to prevent articular penetration, although shorter screws may not be sufficient to support the dorsal articular fragments. Long screws can penetrate the dorsal cortex, which could lead to rupture of the extensor tendons.[18,19]

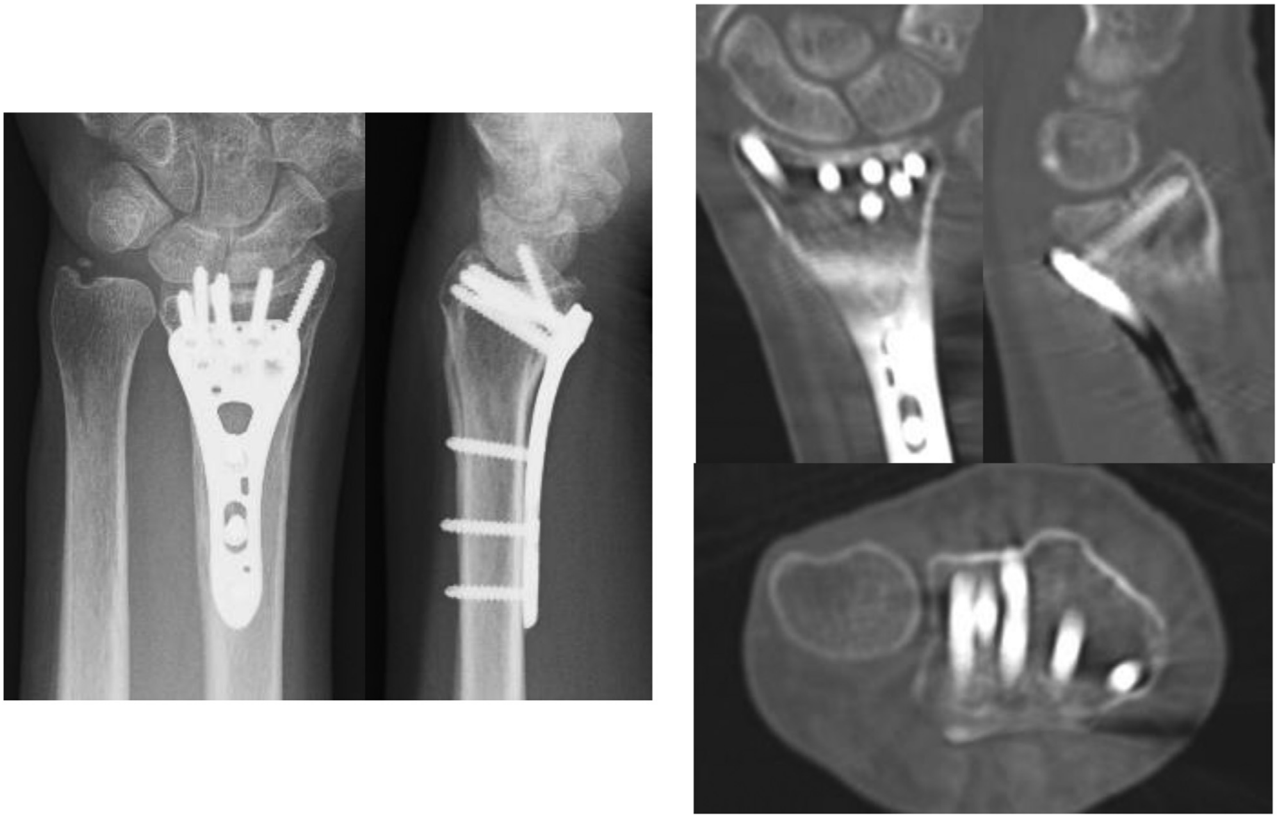

**Figure 5.** Radiographic and CT images at post–bone union.

Obtaining subchondral support, preventing screw penetration into the joints, and precisely inserting a long screw into the dorsal articular fragment are important; however, they are difficult using only fluoroscopic guidance.

Biomechanical studies of the extra-articular distal radius fracture model revealed that 75% distal screw length for the distal fragment could provide sufficient stability.[20,21] However, there are no previous studies on the intra-articular fracture model. Lee et al[22] reported that distal screw insertion close to the articular surface and dorsal rim may be effective in maintaining anatomical reduction; the authors advocated double-tiered subchondral support fixation. Diong et al[23] reported that CT revealed a high incidence of dorsal screw penetration that was not evident on plain radiography, but reported no tendon rupture. They recommended unicortical screw insertion near the cortex, while describing that bicortical fixation may be desirable in osteoporotic patients with displaced dorsal fragments. Thus, it is valid to insert a screw as close as possible to the dorsal cortex for intra-articular fractures in elderly patients such as those included in our study.

Intra-articular screw penetration must be avoided after volar locking plate fixation for the repair of distal radius fractures.[18,24] Pace and Cresswell[25] reported screw penetration in 8 of 128 cases (6.3%) using radiographic articular wrist views, and Gyuricza et al[26] reported that 3 of 28 cases with plate removal (10.7%) resulted from intra-articular screw penetration. Further, Knight et al[27] reported screw penetration of the radiocarpal joint in 11 of 40 cases (27.5%) at the final follow-up as a consequence of postoperative collapse. There was no instance of screw penetration in our study, because the proposed intraoperative CT-guided navigation technique allows precise screw insertion and the detection of intra-articular screw penetration during surgery. Theoretically, our intraoperative CT-guided navigation procedure could prevent intra-articular screw penetration.

The dorsoulnar fragments in the intra-articular distal radius fractures are components of the radiocarpal and distal radioulnar joints; therefore, it is important to reduce and fix the fragments accurately. Our CT-guided navigation procedure is intended for accurate screw insertion, especially for dorsal fragments. In the current study, the screws were positioned an average of less than 2 mm from the articular surface and less than 1 mm from the dorsal cortex. Notably, dorsal articular fragments can be fixed by using long screws near the joint surface and dorsal cortex. On postoperative CT evaluation, the intra-articular fragments maintained acceptable reduction and achieved bone union. The precise insertion of screws into the reduced dorsal fragments led to stable fixation of these fractures and avoided the potential use of additional fixation such as dorsal plating.[28,29]

The drawbacks of CT-guided navigation are the high costs of the medical equipment and prolonged surgical time. Moreover, radiation exposure and the accuracy of the navigation should be considered. Computed tomography–guided navigation is in high demand at our institution and is used frequently in spine, tumor, and brain surgery in addition to fracture surgery. A cost-effective assessment is required for all surgeries across the institution, not just for our patients. Mean surgical time in the CT navigation group was longer than that for the conventional volar plate fixation procedure. However, with experience, we were able to complete the procedure within 2 hours in our more recent cases. We consider this an acceptable duration given the low risk of infection.[30] Regarding radiation exposure, surgeons are not exposed to CT radiation because they leave the operating room when CT images are taken. In spinal surgery, intraoperative CT-guided navigation was

**Table 4**
Dose-Length Product (DLP) of CT

| | Before Surgery | During Surgery | After Bone Union | Chest | Abdominopelvic |
|---|---|---|---|---|---|
| DLP, mGy · cm | 128.5 (±97.6) | 84.7 (±36.4) | 124.4 (±62.8) | 258–381* | 360–433* |

* Previous report.

reported to increase radiation exposure to patients and reduce that to the surgeon.[31,32] In this study, both intraoperative CT radiation exposure and the total dose of CT were not much greater than those of chest or abdominopelvic CT reported in a previous study[33] (Table 4). We consider patients' radiation exposure in this study to have had little adverse effect. Regarding accuracy, precise screw insertion is achievable owing to the capability of the navigation procedure to predict the exact screw position. In addition, confirmation of the plate position using an image intensifier before screw insertion can improve the procedural accuracy. We believe that our CT-guided navigation procedure will be useful in supporting conventional fluoroscopy.

A limitations of this study was the small sample size of the CT navigation group. Because of incomplete follow-up, we were unable to compare outcomes or radiographs between controls and the CT navigation group, so only complications were examined. In the control group, the same CT evaluation as in the CT navigation group could not be performed because immediate postoperative CT was unavailable. Furthermore, many patients, even those with complications, did not have sufficient follow-up or lacked sufficient clinical evaluation in the control group. Therefore, whether improper screw insertion affects clinical outcome could not be discussed in the study. Considering that recent results of volar locking plate fixation using fluoroscopy were extremely good,[34] the clinical results in this study would not surpass that. Nevertheless, misplaced screws in fluoroscopic surgery cannot be prevented and have been reported as a complication requiring reoperation.[35] The main benefits of the proposed CT-guided navigation procedure are accurate screw insertion and immediate intraoperative confirmation of reduction of the intra-articular fragments and the screw position. This may be useful in preventing screw misplacement and improving fracture stability without additional fixation.

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