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Original Article

Usefulness of CT-based measurement of volar prominence for evaluation of risk of flexor tendon injury following fixation of a distal radius fracture

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ABSTRACT

Background: Although some radiographic evaluations of the risk of flexor tendon injury following fixation of a distal radius fracture are useful, these radiographic measurements are limited because of their inability to obtain three-dimensional measurements. We hypothesized that CT-based measurements would be more sensitive indicators for risk estimation than radiography.

Methods: We retrospectively evaluated the relationship between plate positioning and the incidence of flexor tendon symptoms based on postoperative radiographic and CT-based measurements in 99 hands that were followed up for more than 12 months. We also compared the reproducibility, diagnostic accuracy, and ability to detect the plate-bone gap between radiographic and CT-based measurements. We also assessed the correlation between the volar prominence and plate-bone gap using CT. Multivariable analysis using stepwise logistic regression was performed to identify factors independently associated with tendon rupture or irritation.

Results: In single variable analysis, we found that the volar tilt was significantly smaller and the radiographic plate-to-critical line distance (PCL), CT-PCL, and CT-gap were significantly greater in the group with tendon irritation or rupture. Multivariable logistic regression analysis indicated that the CT-based measurement of the volar prominence is a significantly positive independent predictor of tendon rupture or irritation.

Conclusion: CT-based measurement of the volar prominence may be one of the best radiographic predictors of the risk of flexor tendon injury following fixation of a distal radius fracture regardless of the plate type and distal prominence and the extent of rotation. This measurement may assist surgeons when deciding on the need for removal of hardware to decrease the long-term risk of flexor tendon rupture.

1. Introduction

Complications have been reported after volar locking plate fixation for fracture of the distal radius. Delayed rupture of the flexor tendon is a particularly severe complication [1] with a reported incidence of 0.8%–12% [2–5], and usually occurs because of incorrect plate positioning, screw prominence, poor plate design, loss of reduction, or fracture collapse [3,6–9].

Soong et al. [9] retrospectively reviewed plate positioning on lateral radiographs and reported that implant prominence at the watershed line on the distal part of the radius might increase the risk of tendon injury. The Soong grading system has been used in several studies as a predictor of tendon rupture. Kitay et al. [10] recommend selective removal of hardware after union in symptomatic patients with a plate prominence >2.0 mm volar to the critical line and in those in whom the plate is positioned within 3.0 mm of the volar rim. These recommendations represent a quantitative evaluation of the risk of flexor tendon injury following

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fixation of a distal radius fracture. Tokutake et al. [11] and Yamazaki et al. [12] have reported that the plate-to-critical line distance (PCL) measured on radiography can quantify the volar prominence of the plate and is a better indicator of the risk of flexor tendon injury than the Soong grading system.

Both Soong et al. and Kitay et al. define the most appropriate lateral view as the radiograph in which the plate profile is the narrowest and the pisiform projects over the distal part of the scaphoid. However, it is sometimes difficult to satisfy both of these conditions and it is often difficult to choose an appropriate lateral view. Furthermore, Limthongthang et al. [13] found in their three-dimensional computed tomography (CT) study that the thickness of the prominent profile of the volar plate beneath the path of the flexor pollicis longus (FPL) tendon ranged between 0.6 mm and 1.2 mm for several of the plates used at present despite almost all of the specimens being classified as Soong grade 0. They concluded that there was potential for development of gliding friction between the plate and the FPL despite a grade 0 position on the lateral radiograph. Therefore, we hypothesized that CT-based measurements would be more sensitive indicators for risk estimation than radiography. To verify this hypothesis, we used radiography and CT to investigate the relationship between the incidence of postoperative flexor tendon irritation or rupture and the imaging findings with regard to placement of the volar locking plate.

2. Patients and methods

The protocol for this study was approved by the institutional review board at our hospital and an opt out consent strategy was used. We retrospectively reviewed the electronic medical records for 503 hands of patients who underwent volar locking plate fixation for a distal radius fracture at our institution between October 2005 and August 2015. Only patients who underwent postoperative CT and were followed up for more than 12 months were selected. We investigated the relationship between the incidence of irritation or rupture of the flexor tendon and postoperative findings regarding the volar locking plate position on radiography and CT. We used radiography and CT findings taken at 6 months or later to measure the plate position. Symptoms of flexor tendon irritation were defined as pain, discomfort, or subdermal crepitus around the wrist when moving the fingers and tendon irritation was judged as positive when symptoms had persisted for 6 months or longer [14]. Ninety-nine hands (94 patients) were finally included in the analysis. There was no significant difference in sex or type of fracture between the patients who were included in the analysis and those who were not, except for age (Table 1). Seventeen hands (17.2%) were noted to have irritation or rupture of the flexor tendon (designated the IR group); 5 (5.1%) of these hands were confirmed to have a rupture of the FPL tendon. All cases of rupture of the flexor tendon occurred in patients who had undergone fixation for a displaced distal radius fracture at our institution. The remaining 82 hands (82.8%) did not exhibit tendon irritation or rupture (designated the non-IR group; Fig. 1). There was no significant difference in age, sex, type of fracture, or follow-up duration between the IR and non-IR groups; however, there was a significant difference in the type of plate used, in particular use of the Acu-Loc VDR plate and Acu-Loc2 proximal VDR plate (AcuMed, Hillsboro, OR, USA; Table 2). The PCL and plate-to-volar rim distance (PVR) were measured as the plate position on radiographs of the lateral wrist taken postoperatively in accordance with the protocol described in a previous report [10]. Using the method described by Soong et al. [9] and Kitay et al. [10], the lateral view that showed the narrowest projection of the plate was selected as the most appropriate radiographic view for assessment of the plate position, and projection of the pisiform over the distal part of the scaphoid was confirmed when possible. In addition to the radiographic PCL and PVR measurements, corresponding CT-based measurements (CT-PCL and CT-PVR) and measurement of the gap between the plate and bone (CT-gap) were performed on sagittal images acquired at 55% of the maximal width of the radius, starting from the volar-ulnar corner, according to the protocol described in previous anatomic reports on FPL (Fig. 2) [13,15]. We also assessed the difference and the systematic error between radiographic PCL and CT-PCL. In addition, the gap between the plate and the volar cortical bone was evaluated on radiographs and on axial or sagittal CT images and described as no gap, complete gap, or partial gap (ulnar, radial, or central). Complete contact was then defined as no gap or center-only gap and incomplete contact was described as a complete gap or partial gap on the ulnar or radial side (Fig. 3). We also assessed the correlation between CT-PCL and CT-gap.

Postoperative CT was performed with the wrist in the neutral position and a slice thickness of 0.5 mm using an Aquilion 16 Multislice CT system (Toshiba Medical Systems, Tochigi, Japan). The radiographic and CT measurements were performed using the picture archiving communication system by three orthopedic surgeons blinded to all information regarding each patient's symptoms. We calculated the interobserver and intraobserver reliability values for PCL, PVR, CT-PCL, CT-PVR, and CT-gap to check their reproducibility.

For the statistical analysis, the means for continuous variables and unpaired proportions of categorical variables were compared using the Mann–Whitney *U* test and Pearson's chi-square test, respectively. We used intraclass correlation coefficients to judge the interobserver and intraobserver reliability of continuous variables. Unpaired proportions were compared between CT and radiographic measurements using McNemar's test. The differences and systematic error between CT-PCL and radiographic PCL were compared using Bland-Altman analysis [16]. The correlation between CT-PCL and CT-gap were compared using Spearman's rank–correlation coefficient. Multivariable analysis using stepwise logistic regression was performed to identify factors that were independently associated with tendon rupture or irritation. We derived the odds ratios (ORs) and 95% confidence intervals (CIs) for relevant factors. We also calculated the diagnostic accuracy and cutoff values for relevant factors using receiver-operating characteristic curve analysis and the Youden index. The threshold for statistical significance was set at $p < 0.05$.

Table 1
Comparison of the demographic and clinical characteristics of 503 hands that were and were not included in the analysis.

Characteristic	Analyzed (n = 99)	Not analyzed (n = 404)	*p*-value
Age, years	62.0 (52–72)	58.0 (46–71)	0.02[a]
Female sex	77 (77.8%)	280 (69.3%)	0.09
Fracture type (AO)			0.10
A	35 (35.4%)	169 (41.9%)	
B	3 (3.0%)	30 (7.4%)	
C	61 (61.6%)	205 (50.7%)	

The data are presented as the median (interquartile range) or n (%).
[a] Significant difference.

3. Results

In single variable analysis of the values measured by both imaging modalities, the volar tilt was significantly smaller ($p = 0.008$) and the radiographic PCL, CT-PCL, and CT-gap values were significantly greater ($p < 0.001$) in the IR group. However, there was no significant difference in ulnar variance or PVR (radiographic or CT) between the two groups (Table 3). In addition, the intraobserver reliability for the three observers were greater than 0.90 for all measurements and the interobserver reliability for these observers

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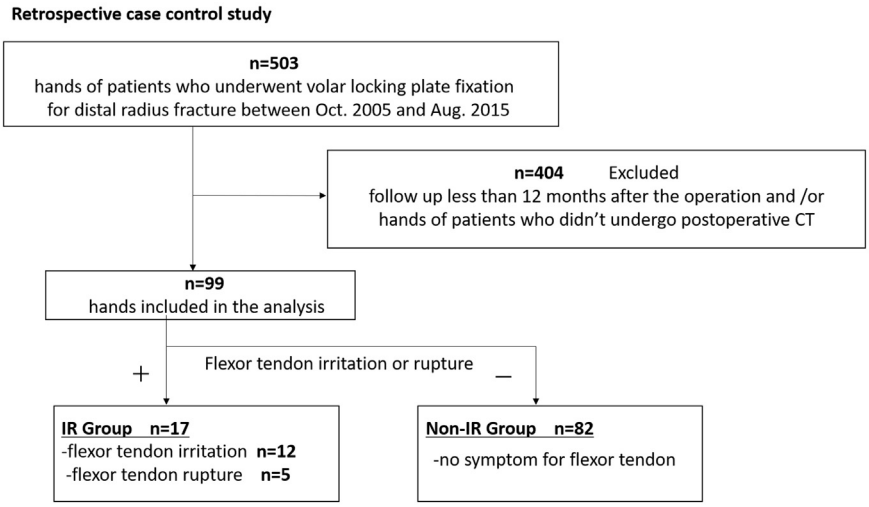

Fig. 1. Flow chart showing the patient enrollment process.

Table 2
Demographic and clinical characteristics of 94 patients (99 hands) who underwent volar locking plate fixation for a fracture of the distal radius.

Characteristic	IR group (n = 17)	non-IR group (n = 82)	*p*-value
Age, years	61.4 (57–72)	59.1 (50–72)	0.79
Female sex	12 (70.6%)	65 (79.3%)	0.64
Follow-up duration, months	14 (12–53)	13 (12–16)	0.092
Plate system			<0.001[a]
Acu-Loc	7	11	
Acu-Loc2 standard	4	14	
Acu-Loc2 proximal	2	46	
VA-TCP	2	9	
Other	2	2	
Fracture type (AO)			0.43
A	8 (47.1%)	27 (32.9%)	
B	0 (0%)	3 (3.7%)	
C	9 (52.9%)	52 (63.4%)	

The data are presented as the median (interquartile range) or n (%). Acu-Loc, Acu-Loc VDR plate; Acu-Loc2 standard/proximal, Acu-Loc2 VDR plate (AcuMed, Hillsboro, OR, USA); VA-TCP, 2.4-mm variable-angle LCP 2-column volar distal radius plate (Synthes GmbH, Oberdorf, Switzerland).
[a] Significant difference.

was also generally high, although the intraclass coefficient (ICC, 2.1) for radiographic PVR was slightly lower (PCL 0.99, PVR 0.71, CT-PCL 0.98, CT-PVR 0.96, and CT-gap 0.93, respectively).

There was a significant difference in the measurements of volar prominence (radiographic PCL and CT-PCL) between the groups, and Bland-Altman analysis revealed a systematic (addition) error between the two sets of measurements. The CT-PCL was significantly greater than the radiographic PCL ($p < 0.001$; mean difference for all patients, 1.13 mm; Fig. 4). There was also a strong correlation between the CT-PCL and CT-gap ($r = 0.696$, $p < 0.001$).

In the subsequent evaluation of plate lifting, the gap between the plate and the volar cortical bone was judged to be incomplete in 41 cases (41.4%) according to CT findings, but in only 15 cases (15.2%) according to radiographic findings ($p < 0.001$). A partial gap on the ulnar side was most frequently noted on CT images (30/41 cases; Table 4). The disagreement in plate-bone contact (complete vs. incomplete) between the radiographic and CT findings was statistically significant (32.3%, $p < 0.001$; Table 5).

Using logistic regression analysis with stepwise logistic regression (objective variable, presence or absence of flexor tendon rupture or irritation; explanatory variables, CT-PCL and CT-gap), we identified the CT-PCL (CT-based measurement of volar prominence)

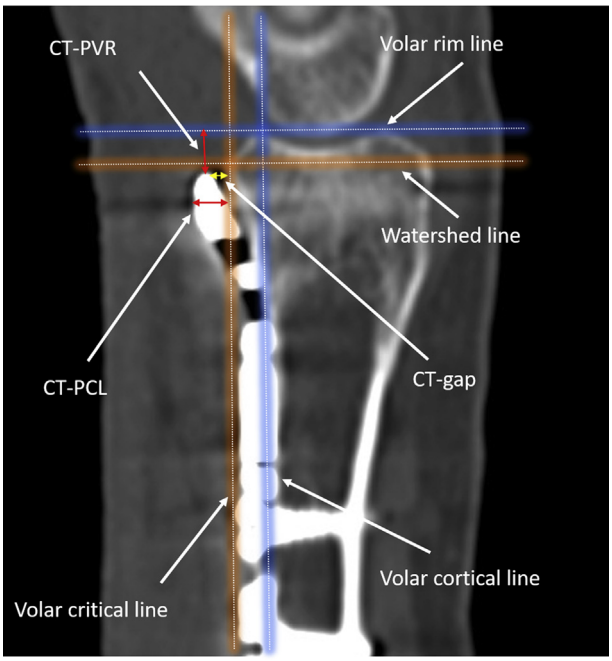

Fig. 2. Sagittal view on a CT scan at the anatomic point of the flexor pollicis longus tendon, illustrating the measurements of CT-PCL, CT-PVR, and CT-gap. CT, computed tomography; PCL, plate-to-critical line distance; PVR, plate-to-volar rim distance.

as a significant positive independent predictor of tendon rupture or irritation ($p = 0.04$, OR 2.4, 95% CI 1.04–5.52; Table 6).

The receiver-operating characteristic curve analysis for CT-PCL, CT-gap, and radiographic PCL revealed respective areas under the curve of 0.89, 0.88, and 0.84 (Fig. 5). Table 7 shows the diagnostic accuracy and cutoff values using the Youden index for all three measurements associated with irritation or rupture of the flexor tendon following fixation of a distal radius fracture. In 2 (11.8%) of the 17 cases in the IR group, the radiographic PCL was <2.0 mm whereas the CT-PCL was >2.5 mm.

4. Discussion

Our single variable analysis indicated that volar tilt and radiographic PCL (radiography-based measurements) and CT-PCL and

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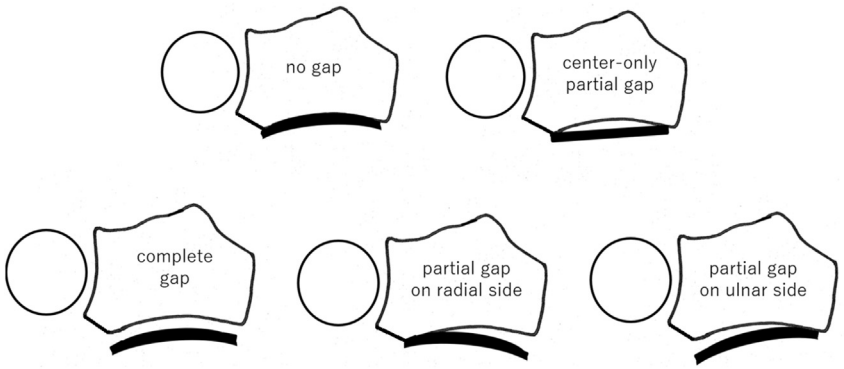

Fig. 3. Pattern of contact between plate and volar cortical bone (complete plate contact, no gap and center-only partial gap; incomplete plate contact, complete gap and partial gap on the radial or ulnar side).

Table 3
Morphologic features and postoperative radiologic findings in 99 hands of 94 patients who underwent volar locking plate fixation for a fracture of the distal radius.

Feature	IR group (n = 17)	non-IR group (n = 82)	*p*-value
Volar tilt, degrees	6 (4–10)	10 (5–13)	0.008[a]
Ulnar variance, degrees	0.5 (−1.2, 1.5)	1.1 (−1.1, 2.2)	0.26
Radiographic PCL, mm	2.9 (2.4–3.5)	1.0 (0–2.2)	<0.001[a]
Radiographic PVR, mm	3.3 (2–4.8)	3.2 (2–4.2)	0.62
CT-PCL, mm	3.9 (3.2–5.0)	2.1 (1.6–3.0)	<0.001[a]
CT-PVR, mm	4.8 (4.2–6.9)	5.2 (4.1–7.0)	0.75
CT-gap, mm	2.4 (1.7–3.1)	0 (0–1.5)	<0.001[a]

The data are presented as the median (interquartile range) or n (%); CT, computed tomography; PCL, plate-to-critical line distance; PVR, plate-to-volar rim distance.
[a] Significant difference.

CT-gap (CT-based measurements), but not ulnar variance or PVR, are effective predictors of the risk of flexor tendon injury following fixation of a distal radius fracture.

Table 4
Distance between the plate and volar cortical bone based on radiographic and CT findings in 99 hands of 94 patients who underwent volar locking plate fixation for a fracture of the distal radius.

Distance parameter	Radiography (n = 99)	CT (n = 99)
No gap	84 (84.8%)	53 (53.5%)
Partial gap		
Ulnar side	–	30 (30.3%)
Radial side	–	4 (4.0%)
Center only	–	5 (5.1%)
Complete gap	15 (15.2%)	7 (7.1%)
Complete plate contact (no gap or center-only partial gap)	84 (84.8%)	58 (58.6%)
Incomplete plate contact (complete or ulnar/radial partial gap)	15 (15.2%)	41 (41.4%)

The data are presented as the number (percentage). CT, computed tomography.

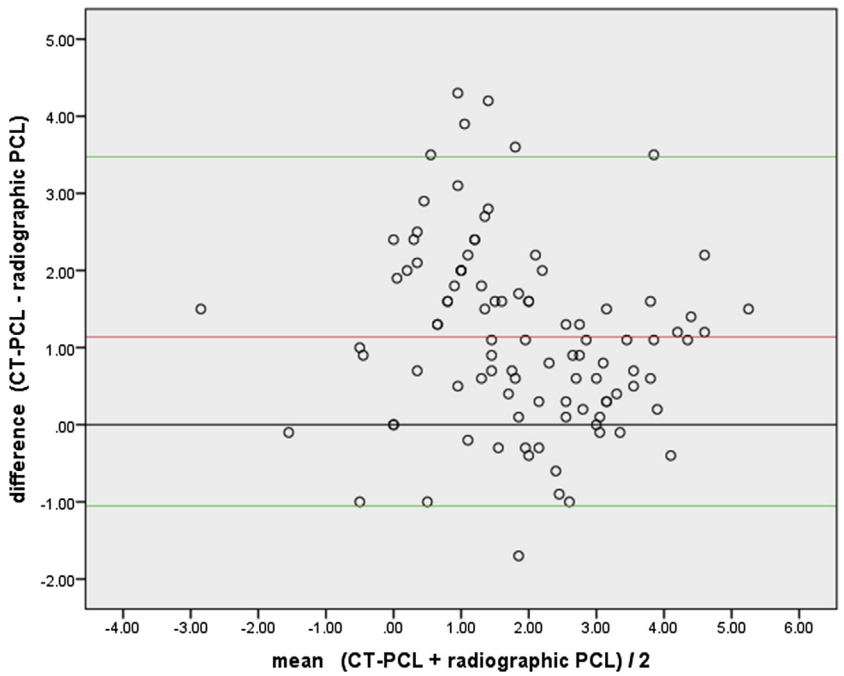

Fig. 4. Bland-Altman analysis of the radiographic PCL and CT-PCL. The red line indicates the mean difference between the radiographic PCL and CT-PCL (1.13 mm; $p < 0.001$). The green line indicates the mean ± 1.96 SD (upper, 3.47 mm; lower, −1.06 mm). CT, computed tomography. PCL, plate-to-critical line distance; SD, standard deviation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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Table 5
Comparison between radiography and CT findings regarding contact between the plate and volar cortical bone in 99 hands of 94 patients who underwent volar locking plate fixation for a fracture of the distal radius.

Finding	CT findings			*p*-value
	Complete plate contact	Incomplete plate contact	Total	
X-ray radiography				
Complete plate contact	55	29	84	
Incomplete plate contact	3	12	15	
Total	58	41	99	<0.001[a]

Complete plate contact was defined as no gap or center-only partial gap and incomplete plate contact was defined as complete gap or partial gap on the ulnar or radial side.
[a] Significant difference; McNemar's test. CT, computed tomography.

Table 6
Significant CT-based measurements associated with irritation or rupture of the flexor tendon following distal radius fracture fixation using multiple regression analysis.

Factor	Odds ratio	95% Confidence interval	*p*-value
CT-PCL	2.40[b]	1.04–5.52	0.04[a]
CT-gap	2.36[b]	0.97–5.71	0.06

CT, computed tomography; PCL, plate-to-critical line distance.
[a] Significant difference.
[b] For every 1.0 mm.

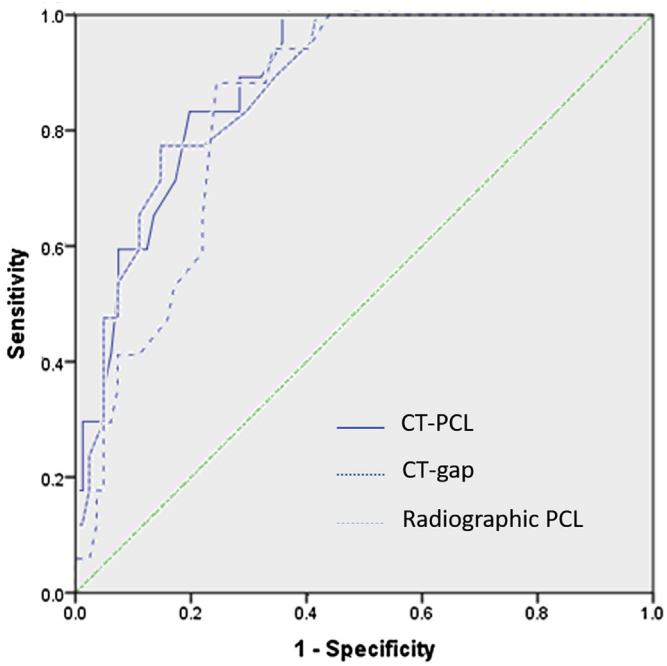

Fig. 5. Receiver-operating characteristic curve analysis of CT-PCL, CT-gap, and radiographic PCL revealed respective areas under the curve of 0.89, 0.88, and 0.84, respectively. AUC, area under the curve; CT, computed tomography; PCL, plate-to-critical line distance.

Table 7
Diagnostic accuracy and cut-off value using the Youden index for three measurements associated with irritation or rupture of the flexor tendon following distal radius fracture fixation.

Factor	AUC	Sensitivity	Specificity	Cut-off value
CT-PCL	0.89	1.0	0.67	2.5
CT-gap	0.88	0.77	0.85	1.8
Radiographic PCL	0.84	0.88	0.76	2.2

AUC, area under the receiver-operating characteristic curve; CT, computed tomography; PCL, plate-to-critical line distance.

In this study, we used PCL and PVR as indicators of the plate position rather than the Soong grading system. The Soong grading system is simple and useful for describing the position of volar plates, but it is essentially a qualitative tool. Soong grade 1 includes various degrees of volar prominence (from mild to severe), whereas Soong grade 2 inevitably implies unacceptable volar prominence. Yamazaki et al. [12] demonstrated that the PCL value for volar placement of hardware in lateral radiographs, but not the Soong grading system, was a significant independent risk factor for attrition of the flexor tendon after volar plating for a distal radius fracture. Therefore, we selected quantitative measurements (PCL and PVR) to obtain detailed information on the plate position.

In the present study, we found that our newly defined CT-based measurements (CT-PCL, CT-PVR, and CT-gap) were reliable tools, as were the radiographic findings (PCL and PVR). Moreover, we found that CT-based measurement had more sensitive ability to detect incomplete plate-bone contact than radiography and the CT-gap was significantly greater in the IR group than in the non-IR group in single variable analysis. Furthermore, assuming that radiographic PCL has true value because it has been validated [10,12], we demonstrated that CT-PCL has systematic (especially addition) error and was significantly greater than the radiographic PCL ($p < 0.001$; mean difference in all patients, 1.13 mm). There was also a strong correlation between the CT-PCL and CT-gap ($r = 0.696$, $p < 0.001$); on the basis of this finding, we assume that this is one of the reasons why the CT-PCL was greater than the radiographic PCL. The presence of a partial gap can be missed easily on radiography and selection of an appropriate lateral radiograph may be difficult if the plate has detached from the bone at the radial or ulnar margins. From these results, we suspect that CT-based measurements would provide additional information regarding whether to remove the implant.

In logistic regression analysis using stepwise logistic regression (explanatory variables, CT-PCL and CT-gap), we demonstrated that CT-PCL is a significant positive independent predictor of tendon rupture or irritation ($p = 0.04$, OR 2.40, 95% CI 1.04–5.52). CT-gap showed a similar trend, but was not significantly different ($p = 0.06$, OR 2.36, 95% CI 0.97–5.71). We think that the reason for this may be that the CT-PCL shows the distance of the volar prominence including both the thickness of the plate and the distance of the gap. Therefore, we believe that CT-PCL would be one of the best radiographic predictors of the risk of flexor tendon injury following fixation of a distal radius fracture regardless of the type of plate, distal prominence, or extent of rotation.

However, unlike radiography, CT has disadvantages in terms of cost and radiation exposure. Therefore, we consider that postoperative CT does not need to be performed when the volar prominence is obvious on a radiograph. The results of this study indicate that CT-PCL has very high sensitivity but moderate specificity. Moreover, the receiver operating characteristic curve analysis for CT-PCL revealed an area under the curve of 0.89; this

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value was the highest of all the radiographic predictors, although there was little difference between the CT-PCL and radiographic PCL. One of the reasons for this may be that the IR group did not include all patients with tendon injury or who will have tendon irritation or rupture in the future; this is the major limitation of this study and reflects the short follow-up duration, definition of tendon injury used, and the retrospective study design. Tokunaga et al. [17] recently demonstrated on ultrasound examination and assessment of the findings at implant removal that erosion of the flexor tendon developed asymptomatically even in patients who had no symptoms until plate removal. It has also become apparent recently that rupture of the flexor tendon sometimes occurs up to 5–10 years after the initial operation, even in patients without symptoms and in those who are not aware of any symptoms [18]. Although we consider that patients should be observed carefully over a long period of time for symptoms, including crepitus, and by ultrasound examination, many patients are unwilling to attend hospital appointments for long-term follow-up because most distal radius fractures have a good outcome with minimal or no symptoms. We found in our study that in 2 (11.8%) of the 17 cases in the IR group, the radiographic PCL was <2.0 mm whereas the CT-PCL was >2.5 mm. Therefore, considering the long-term risk of rupture of the flexor tendon, we recommend CT-PCL as a useful tool for deciding whether or not to strongly recommend selective removal of hardware when a patient do not want to undergo long-term follow-up. This strategy may reduce further the risk of flexor tendon injury following a fracture of the distal radius.

The present study has several limitations over and above the possibility that the non-IR group may have included some asymptomatic patients with frictional wear of the flexor tendon. Firstly, the possibility that there was an effect of selection bias in favor of patients with postoperative CT cannot be excluded. Secondly, the influence of metal artifact on the CT images should be considered. Thirdly, we were unable to evaluate the effect of pronator quadratus repair, which is controversial, especially in elderly patients [19].

Based on our present findings, we expect that many surgeons cannot easily determine the risk of flexor tendon injury on the basis of one radiograph alone and should evaluate the risk carefully using a variety of methods. CT-based measurement of volar prominence may assist surgeons when deciding on the need for removal of hardware to decrease the long-term risk of flexor tendon rupture.

Conflicts of interest

None.

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