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Original article

Impact of two- and three-dimensional computed tomography use on intraobserver and interobserver reliabilities of pilon fracture classification and treatment recommendation

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ABSTRACT

Background: Two-dimensional (2D) and three-dimensional (3D) computed tomography (CT) have been increasingly used in various intra-articular fractures including pilon fracture. However, no study has investigated intraobserver and interobserver reliabilities of pilon fracture classification using 3D CT images.

Hypothesis: (1) Intraobserver and interobserver agreements of fracture classifications and treatment recommendations will improve by using 2D CT images compared to using plain radiographs only; (2) agreements will improve by adding 3D CT images compared to adding 2D CT images; and (3) agreements of orthopedic residents rather than specialists will be influenced more by imaging modality.

Materials and methods: Ten orthopedic specialists and 10 residents completed a survey to classify the fractures according to the Rüedi-Allgöwer and AO/OTA classifications and to select treatment options using 25 pilon fracture images. The survey was conducted using plain radiographs, with 2D and 3D CT images introduced 3 and 6 weeks later, respectively. Kappa coefficients were calculated to determine reliabilities.

Results: Intraobserver reliabilities for fracture classifications in specialists significantly improved by using 2D images compared to using plain radiographs only. Addition of 3D CT did not significantly improve intraobserver reliabilities compared to those with 2D CT. Use of 2D CT images significantly improved overall interobserver agreement of both classifications, with the improvement being greater for residents. Use of 3D CT images did not improve the interobserver reliability of both classifications. Overall interobserver reliabilities for treatment recommendations did not significantly differ according to the imaging modality. However, interobserver agreement among residents significantly improved from slight agreement using radiographs only to fair agreement using 2D CT images.

Discussion: Intraobserver and interobserver reliabilities of pilon fracture classification and treatment recommendations did not improve between using 3D and 2D CT. Using 2D CT images improved the intraobserver and interobserver reliabilities of the fracture classifications in specialists and the interobserver reliabilities of the fracture classifications and the treatment recommendations in residents.

Level of evidence: IV, case control study.

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; CT, computed tomography.

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1. Introduction

The main objective of pilon fracture treatment is to restore congruency of the articular surface as in other intra-articular fractures [1–3]. For anatomic reduction of the articular surface, precise evaluation and accurate understanding of the fracture pattern are necessary [4]. The Rüedi-Allgöwer [5] and Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) [6] classifications have been used to classify pilon fractures. However, unsatisfactory reliabilities for these classifications have been reported with use of plain radiographs and two-dimensional (2D) computed tomography (CT) images [7–9]. 2D and three-dimensional (3D) CT have been increasingly used in various intra-articular fractures, and their role has been evaluated [10–12]. Furthermore, the usefulness of 2D CT in preoperative planning [4], in determining reliabilities of the classifications [8,13], and in clinical results [14] of pilon fractures has also been investigated.

However, to the authors' best knowledge, no study has investigated intraobserver and interobserver reliabilities of pilon fracture classification using 3D CT images. Moreover, improvement in these values with the use of 2D CT images compared with the use of plain radiographs alone has not been well investigated.

Therefore, the questions of the current study were as follows:

- whether 2D and 3D CT will affect the intraobserver and interobserver reliabilities of fracture classifications and treatment recommendations for pilon fractures;
- whether the effect of imaging modality on the reliability may differ according to the surgeons' experience.

The hypotheses were as follows:

- reliabilities of the fracture classifications and treatment recommendations will improve by using 2D CT images compared to using plain radiographs only;
- reliabilities will improve by adding 3D CT images compared to adding 2D CT images;
- using 2D and 3D CT images, reliabilities would show more improvement in orthopedic residents than in specialists.

2. Patients and methods

The study was performed after obtaining approval from the institutional review board (registration number and ID: 2018-01-044/Date of Issue: 7th Feb 2018).

2.1. Patients

The inclusion criteria were as follows: distal tibial intra-articular fracture (43 B and C type fractures by AO/OTA classification) with anteroposterior, lateral, oblique, and mortise ankle plain radiographs, 2D CT images in the axial, coronal, and sagittal planes, and 3D CT images obtained within 1 week of initial trauma. Between 2013 and 2015, 32 pilon fractures were treated in our hospital. The exclusion criteria were as follows: those who underwent previous operations on the affected ankle (1 case); inadequate plain radiographs or CT images (2 cases); without CT scan (4 cases). Finally, 25 pilon fractures were analyzed.

2.2. Acquisition of CT images

All CT images were obtained using Optima CT 660 scanner (GE healthcare, Milwaukee, WI, USA) with 2-mm thick slices at the same hospital. Coronal and sagittal 2D reconstructions were performed on the scanner and volume-rendering 3D image reconstruction on a separate GE Advantage workstation (Fig. 1).

External fixation was performed in cases with open fracture of Gustillo-Anderson type II or more (3 cases) or those with subluxated ankle (2 cases) or poorly maintained reduction showing protruded bony fragment under the skin even after closed reduction (6 cases). In 11 patients with an external fixator, CT scan was performed after external fixation. For remaining patients, CT was performed after closed reduction and splint application by an orthopedic surgeon.

2.3. Survey methods

All identifying data, including age and sex, were obscured for blinded evaluation. Twenty independent investigators, including 10 orthopedic specialists (6 general orthopedics, 4 university hospital orthopedic surgeons including 2 with other specialty rather than traumatology/foot and ankle, 1 traumatologist, and 1 foot and ankle specialist) and 10 orthopedic residents (4–5 post grad year), completed a survey. The senior author, who treated pilon fracture patients, reviewed and included cases; however, he did not perform surveys to avoid bias.

The survey consisted of three questions per case, with questions for Rüedi-Allgöwer and AO/OTA classifications. Diagrams for each classification were provided (Supplemental data 1). The third question was related to fracture treatment recommendations. The three treatment options were:

- conservative treatment;
- open reduction and internal fixation (ORIF, including arthroscopy-assisted operation);
- closed reduction and internal fixation (CRIF, including minimally invasive plate osteosynthesis).

Initially, the observers classified the fracture pattern and selected a treatment plan using plain radiographs only. Three

Fig. 1. Imaging studies given for the survey. Plain radiographs (a), 2D computed tomography (b), and 3D computed tomography (c) of the pilon fracture given for the survey.

Table 1
Distribution of the Rüedi-Allgöwer and AO/OTA classifications for the pilon fractures.

Case	Rüedi-Allgöwer classification		AO/OTA classification		Treatment recommendation	
	Specialists	Residents	Specialists	Residents	Specialists	Residents
1	I and II (5 each)	I (8)	C1 (10)	C1 (8)	CRIF (8)	CRIF (6)
2	I (7)	II (9)	C1 (6)	C1 (5)	CRIF (9)	CRIF (8)
3	III (10)	III (9)	C3 (10)	C3 (10)	ORIF (10)	ORIF (10)
4	III (9)	III (7)	B3 (9)	B3 (6)	ORIF (10)	ORIF (8)
5	I (5)	I and II (5 each)	C1 (7)	C1 (5)	CRIF (6)	ORIF (7)
6	I (6)	I and II (5 each)	B2 (4)	C1 (6)	ORIF and CRIF (5 each)	CRIF (7)
7	II (10)	II (8)	B2 and C1 (4 each)	B2 and C1 (4 each)	ORIF (9)	ORIF (7)
8	III (6)	II and III (4 each)	B3 (4)	C2 (8)	ORIF (9)	ORIF (8)
9	III (7)	III (7)	B3 (6)	B3 (5)	ORIF (10)	ORIF (8)
10	III (10)	III (9)	B3 (7)	C3 (5)	ORIF (10)	ORIF (9)
11	I and II (5 each)	II (7)	C1 (6)	C1 (5)	CRIF (7)	CRIF (6)
12	III (10)	III (10)	C3 (9)	C3 (9)	ORIF (10)	ORIF (7)
13	II (7)	II (6)	B3, C1, C2, and C3 (2 each)	C1 (4)	ORIF (7)	ORIF (8)
14	III (10)	III (9)	C3 (10)	C3 (8)	ORIF (10)	ORIF (8)
15	III (4)	I and II (5 each)	B3 (5)	B1 (4)	ORIF (6)	ORIF (5)
16	I (8)	I (9)	B1 and B2 (5 each)	B1 (5)	Conservative (5)	ORIF (7)
17	III (10)	III (7)	C3 (8)	C3 (6)	ORIF (10)	ORIF (7)
18	III (5)	II and III (5 each)	B3 (6)	B2 (4)	ORIF (10)	ORIF (7)
19	I (8)	I (8)	C2 (7)	C1 (6)	CRIF (9)	CRIF (8)
20	III (7)	III (6)	B3 (6)	B2 and B3 (4 each)	ORIF (10)	ORIF (7)
21	III (8)	III (7)	B3(8)	B3 (4)	ORIF (10)	ORIF (8)
22	I (9)	I (8)	C1 (7)	B1 (6)	CRIF (9)	CRIF (8)
23	III (6)	II (9)	B3 (7)	B3 and C2 (3 each)	ORIF (9)	ORIF (8)
24	I (6)	I and II (5 each)	C1 (9)	C1 (6)	CRIF (8)	CRIF (8)
25	I (6)	II (6)	C1 (5)	C3 (6)	CRIF (7)	ORIF (7)

AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; CRIF: closed reduction and internal fixation; ORIF: open reduction and internal fixation.

weeks later, the same survey was performed using plain radiographs and 2D CT images. After a 3-week interval, the observers performed the survey again using plain radiographs, 2D CT images, and 3D CT images.

To evaluate intraobserver agreement, the same three survey rounds were also performed 3 weeks after the end of the previous survey. Ten orthopedic specialists completed the surveys for intraobserver reliability; however, only five orthopedic residents completed surveys for intraobserver agreement, since remaining five have become specialists without completing survey.

2.4. Statistics

A biomedical statistician performed the analysis. To assess the intraobserver agreement, Cohen's kappa [15] was calculated. Wilcoxon-signed rank test was performed to compare the intraobserver reliabilities with different imaging modalities.

The interobserver reliability was also analyzed. Fleiss kappa [16] coefficients were calculated for the interobserver reliability, as the number of observers was more than two.

For intraobserver reliability, the number of subjects required was calculated as 24, assuming an even distribution of each item, anticipated kappa value of 0.5, and desired type I error rate of 0.05. For interobserver reliability, the number of subjects required was calculated as 21 subjects, assuming 6 observers with an even distribution of each item, anticipated kappa value of 0.4, and desired type I error rate of 0.05. As the number of observers increases, the number of subjects required decreases [17]; thus, the 25 subjects in this study with 10 observers per group have enough power.

According to Landis and Koch [18], kappa coefficients < 0 indicate no agreement; 0.0 to 0.2, slight agreement; 0.21 to 0.4, fair agreement; 0.41 to 0.6, moderate agreement; 0.61 to 0.8, substantial agreement; and 0.81 to 1.0, almost perfect agreement. p-values < 0.05 reflect the likelihood that the intraobserver and interobserver agreements are greater than zero (pure chance alone). All statistical analyses were performed using R Statistical Software version 3.3.0.

3. Results

The distribution of fracture classifications, and treatment recommendations, which selected by the largest number of the residents and specialists, are presented in Table 1.

3.1. Intraobserver reliability

3.1.1. Fracture classification

For the Rüedi-Allgöwer classification, specialists showed moderate agreement with the use of plain radiographs only and substantial agreement with the addition of 2D and 3D CT images (Table 2). Addition of 2D and 3D CT images significantly improved the agreement compared with using plain radiographs only (p = 0.004, 0.046, respectively). Residents showed moderate agreements regardless of imaging modality for the Rüedi-Allgöwer classification (Table 3).

For the AO/OTA classification in specialists was fair with the use of plain radiographs only and moderate with the addition of 2D and 3D CT images. Addition of 3D CT significantly improved the agreement compared with plain radiographs only (p = 0.014). Residents showed fair agreements regardless of imaging modality for the AO-OTA classification (Table 3).

3.1.2. Treatment recommendation

For the treatment recommendations, intraobserver reliability was moderate in the specialists with plain radiographs only and with the addition of 2D and 3D CT images (Table 2). Residents showed fair agreements regardless of imaging modality for the treatment recommendations (Table 3).

3.2. Interobserver reliability

3.2.1. Fracture classification

With the use of plain radiographs only, overall interobserver reliabilities of both fracture classifications showed a fair agreement. Addition of 2D CT images significantly improved the overall

Table 2
Intraobserver reliabilities for pilon fracture among specialists. The values are given as the mean, with the range in parentheses.

Imaging modality	Kappa coefficient		
	Rüedi-Allgöwer	AO/OTA	Treatment
Radiograph only	0.56 (0.43, 0.76)	0.40 (0.24, 0.46)	0.51 (0.36, 0.62)
Radiograph + 2D CT	0.69 (0.56, 0.80)[a]	0.43 (0.23, 0.54)	0.51 (0.23, 0.65)
Radiograph + 2D CT + 3D CT	0.64 (0.46, 0.75)[a]	0.46 (0.27, 0.61)[a]	0.52 (0.15, 0.78)

AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association.
[a] Significant increase in reliability compared to radiograph only.

Table 3
Intraobserver reliabilities for pilon fracture among residents. The values are given as the mean, with the range in parentheses

Imaging modality	Kappa coefficient		
	Rüedi-Allgöwer	AO/OTA	Treatment
Radiograph only	0.46 (0.41, 0.53)	0.32 (0.28, 0.37)	0.33 (0.19, 0.43)
Radiograph + 2D CT	0.56 (0.52, 0.64)	0.36 (0.24, 0.45)	0.35 (0.25, 0.46)
Radiograph + 2D CT + 3D CT	0.58 (0.50, 0.64)	0.37 (0.28, 0.50)	0.34 (0.21, 0.41)

AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association.

interobserver reliability of both classifications ($p < 0.001$ each, respectively). However, the addition of 3D CT images decreased the overall interobserver reliability of both classifications compared with the assessment using plain radiographs and 2D CT images ($p < 0.001$ and < 0.01, respectively, Figs. 2 and 3). Specialists showed significantly higher interobserver agreements for both fracture classifications with plain radiographs than residents ($p < 0.001$ each; Figs. 2 and 3). With addition of 2D and 3D CT images, specialists showed significantly higher interobserver reliability for AO/OTA classification than residents ($p < 0.001$ each; Figs. 2 and 3). Both residents and specialists showed significant improvements in the interobserver agreements of both fracture classifications with the use of 2D CT images ($p < 0.001$ each; Figs. 2 and 3). Improvement in the agreement with the use of 2D CT images was greater among residents than among specialists.

3.2.2. Treatment recommendation

Overall interobserver reliabilities for selecting treatment recommendations were all fair with the use of plain radiographs only, addition of 2D CT images, and addition of 3D CT images; and the change was not significant. Specialists showed moderated agreements in all three survey rounds, which was significantly higher interobserver agreements that residents with all imaging modalities ($p < 0.001$ each; Fig. 4). Among residents, interobserver agreement significantly improved from slight-to-fair agreement with the addition of 2D CT images ($p < 0.001$). Conversely, interobserver reliability among residents significantly decreased with the addition of 3D CT images ($p < 0.05$, Fig. 4).

4. Discussion

In the present study, the additional use of 3D CT images did not improve the reliabilities among the orthopedic surgeons regardless of their levels of experience. The addition of 2D CT images improved the intraobserver reliabilities of the fracture classifications in specialists and the interobserver agreement of the fracture classifications and treatment recommendations among specialists and residents.

CT has been regarded a useful tool for identifying fracture morphology and planning treatment of pilon fractures [4,8,13,19]. Mast et al. [19] showed that CT scans can visualize vertical fractures better than plain radiographs. Tornetta and Gorup [4] revealed that CT scans have advantages in detecting the number of fragments, impaction, and comminution in pilon fractures. Therefore, it can be assumed that using CT will improve the agreement compared with using plain radiographs alone. In the current study CT scans also improved agreements of the fracture classifications.

However, previous studies have revealed that the use of 2D CT images failed to significantly improve the reliability for fracture classifications [8] and showed only a moderate agreement [13]. However, some points should be considered in interpreting the results of previous studies. In the study by Martin et al. [8], 2D CT images were available in only 14 out of 43 cases. In Ramappa et al.'s study [13], reliabilities for fracture classifications using 2D CT images were not compared those using plain radiographs only. Therefore, we considered that definite conclusions on the impact of using 2D CT images on the reliabilities for fracture classifications cannot be drawn from their studies.

Notably, the impact of using 2D CT images on the improvement in the kappa coefficient of the fracture classification was more prominent among the residents than among the specialists. Furthermore, the interobserver agreement of the treatment plans increased only in the residents with 2D CT images. There can be several reasons for this. First, articular fractures not severely displaced or depressed can be identified more easily using CT images than using plain radiographs [7]. Second, specialists who are more experienced than residents are familiar with pilon fractures and their radiographs and classifications. Therefore, residents, who have difficulty in identifying fracture patterns using plain radiographs only, are more likely to benefit from using 2D CT images.

In this study, the addition of 3D CT images was proven to be unhelpful on the reliabilities of fracture classifications. Given that axial loading is the main injury mechanism, identifying depressed articular fragments is the most important step in understanding pilon fracture morphology. Although it is a three-dimensional imaging technique, 3D CT presents the processed image on a 2D plane and only provides visualization of the bone surface. Therefore, it is difficult for 3D CT images to more clearly show the depressed fragments than the sagittal and coronal images of 2D CT. Previous studies evaluating the usefulness of 3D CT images for classification of other fractures also reported that 3D CT provided no benefit [10,11]. However, the significantly worse degree of agreements among residents with the use of 3D CT was unexpected. Considering that the most residents also made similar decisions with specialists (Table 1), different impressions from various imaging modalities might have affected the decision of some inexperienced residents.

In the present study, interobserver agreements of the Rüedi-Allgöwer classification with all imaging modalities showed a higher value than those of the AO/OTA classification. The AO/OTA

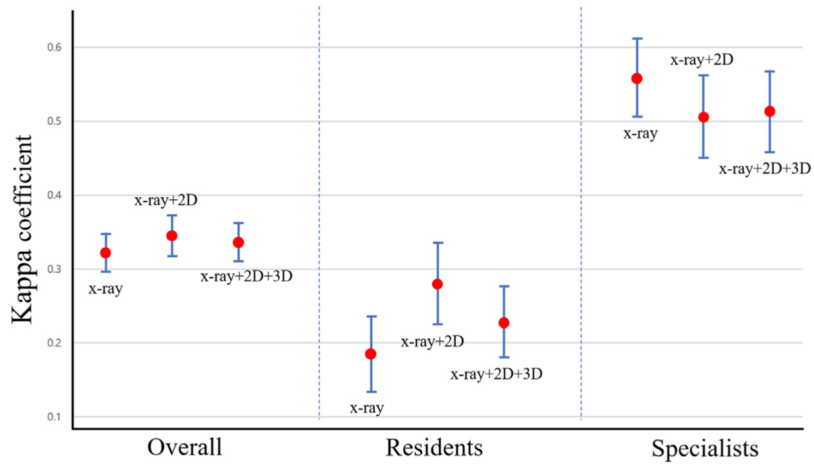

Fig. 4. Interobserver reliability of the treatment recommendations. Red circle indicates the calculated kappa coefficient. Blue line indicates the 95% confidence interval. 2D: two-dimensional computed tomography; 3D: three-dimensional computed tomography.

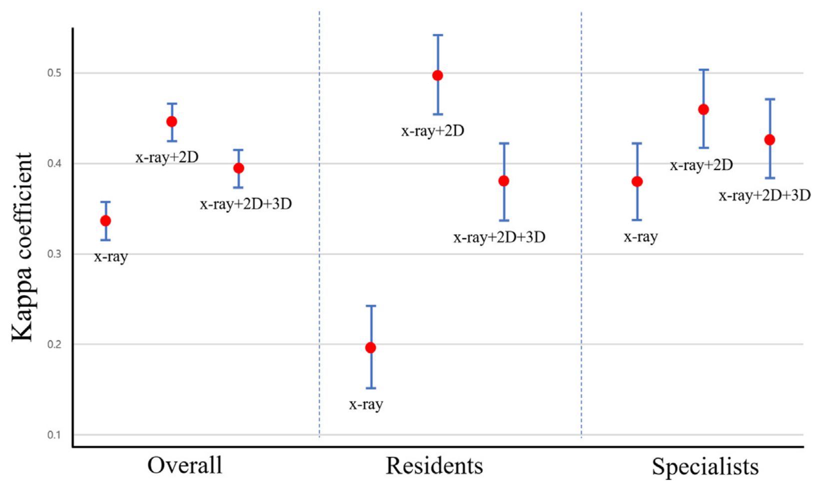

Fig. 2. Interobserver reliability of the Rüedi-Allgöwer classification. Red circle indicates the calculated kappa coefficient. Blue line indicates the 95% confidence interval. 2D: two-dimensional computed tomography; 3D: three-dimensional computed tomography.

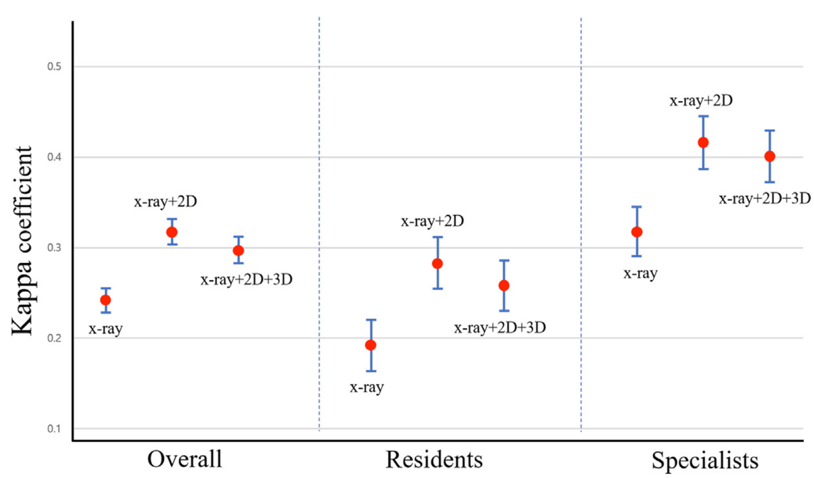

Fig. 3. Interobserver reliability of the AO/OTA classification. Red circle indicates the calculated kappa coefficient. Blue line indicates the 95% confidence interval. 2D: two-dimensional computed tomography; 3D: three-dimensional computed tomography; AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association.

classification is more complex than the Rüedi-Allgöwer classification in terms of metaphyseal morphology and intra-articular part. Therefore, even with its lower agreements, AO/OTA classification can be helpful in planning detailed treatments.

It can be reasoned that using 3D CT images is advantageous for deciding treatment strategies, as these images present more detailed information on the meta-diaphysis. However, in the current study, using 3D CT images did not improve agreements of the treatment recommendations. The oversimplified question may be responsible for this result. Further survey with more detailed consideration of treatment option including specific fixator use or bending of plates is necessary to show usefulness of 3D CT images. Notably, slight-to-fair agreements were found for treatment strategy in residents. This low agreement for treatment choice is mainly due to the difference in opinion on whether to perform CRIF or ORIF in relatively complex articular fractures. Therefore, the importance of anatomic reduction in the treatment of intra-articular fractures in resident education should be emphasized.

This study had several limitations. First, a simple question on the treatment recommendations was used for ease of analysis, which may have affected the results. Furthermore, the treatment option was decided on without clinical data of patients and may have affected the results. Second, only 5 residents completed survey for intraobserver reliabilities. Finally, the fact that less than half of the patients underwent external fixation before CT scan may have affected our results. However, even in patients without external fixation, closed reduction and long leg splint were performed before CT scan to obtain better images and to minimize bias.

5. Conclusion

Using 3D CT images did not improve the intarobserver and interobserver reliabilities of the classification and treatment recommendations for pilon fractures, whereas using 2D CT images improved the intraobserver and interobserver reliabilities of the fracture classifications and interobserver agreement for treatment recommendations. Residents may benefit more than specialists from using 2D CT images.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contributions

S.-E. Byun: study design, data analysis, and manuscript writing.
W. Choi: study conception and design.
Y. Choi: study conception and design, revising manuscript (corresponding author).
T.-K. Ahn: data analysis.
H.K. Kim: data analysis and manuscript writing.
S. Yoon: data acquisition and revising manuscript.
J. Lee: statistical analysis.
D.-S. Choi: data acquisition.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.otsr.2019.07.011.

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