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# Comparison of Radiographic Measurement Parameters of the Wrist in Patients with and without Scaphoid Fracture after Fall on an Outstretched Hand

## Porovnání parametrů radiografického měření zápěstí u pacientů s a bez zlomeniny scaphoidea po pádu na nataženou ruku

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## ABSTRACT

PURPOSE OF THE STUDY

To investigate the effects of anatomical variations on the mechanism of scaphoid fracture by comparing the radiologic parameters of the wrist of patients with and without scaphoid fracture after a fall on an outstretched hand.

MATERIAL AND METHODS

Cross-sectional comparative retrospective analysis of radiographs of patients with (Group 1, n=169) and without scaphoid fracture (Group 2, n=188). Morphometric data were measured including radial inclination (RI), radial height (RH), ulnar variance (UV), carpal height (CH) ratio, revised carpal height (RCH) ratio and palmar tilt of the distal radius (PT). Receiver operating characteristics (ROC) curve analysis was used to assess the diagnostic performance for each variable with statistically significant difference.

RESULTS

The mean RI and PT degrees and RH length were statistically significantly higher, and the mean UV was lower in Group 1 compared to Group 2. No difference was determined between the groups with respect to the CH ratio and RCH ratio. With ROC curve analysis, the cut-off value with the highest odds ratio was determined as RH (Cut-off value=10.77 mm, OR=21.886).

CONCLUSIONS

Although higher RI, RH, PT values and more negative ulnar variance were observed in the scaphoid fracture group compared to the non-fracture group, ROC curve analysis showed that only increased RH can be considered as a possible risk factor for scaphoid fractures after fall on an outstretched hand.

**Key words:** radiographs**,** risk factor, scaphoid fracture, wrist morphology.

## INTRODUCTION

The scaphoid is an important carpal bone that is obliquely oriented on the radial side of the wrist and connects the proximal and distal carpal rows (7). Scaphoid fractures are the most commonly injured carpal bone, accounting for approximately 60–90% of all carpal fractures, and with 10–15% nonunion rate is encountered due to delayed initiation of treatment if undiagnosed, which leads to carpal collapse and consequential arthritis (4, 10, 12). Scaphoid fractures are commonly occur after a fall on an outstretched hand with the wrist in extension (13, 24).

The exact biomechanical mechanism of scaphoid fractures is controversial (8, 26). A cadaveric study has shown that scaphoid fractures are more likely to occur with hyperextension and radial deviation of the wrist (8). Later studies have confirmed these findings and showed that scaphoid fractures occur by applying a load on the radial part of the palm with the wrist only at 95 to 100 degrees of extension (26). With the wrist in extension, the scaphoid contacts the dorsal rim of the radius and body weight is transferred to the scaphoid with axial loading along the radius shaft. In this position the proximal pole of the scaphoid is stabilized by the taut palmar capsule, however the distal pole, which is not supported by capsular structures, is lax. Therefore, the failure of the scaphoid usually occurs in the waist, which is the point that receives the highest bending moment (9, 25).

Whether a scaphoid fracture will occur after a fall on an outstretched hand depends mostly on the magnitude and direction of the force to which the bone is exposed, but other factors such as the quality of the bone, the strength of the surrounding muscles and ligaments, and the shock-absorbing capacity of the palmar soft tissues and anatomic variations may also play a role. Anatomical characteristics such as ulnar variance, radial inclination, volar tilt, and carpal height may affect the intensity and direction of the loads transferred to the wrist (15, 27). However, the effect of these factors on the development of scaphoid fracture is not clear and there are limited studies on this subject in the literature (3, 19).

The hypothesis of this study is that wrist morphometric parameters may be effective risk factors for the development of scaphoid fracture.

The aim of our study was to investigate the effects of anatomical variations on the mechanism of scaphoid fracture by retrospectively comparing the radiologic parameters of the wrist of patients with and without scaphoid fracture after a fall on an outstretched hand.

## MATERIAL AND METHODS

### Study design and subjects

Approval for this study was granted by the Institutional Ethics Committee and informed consent waived for the retrospective review of medical records (IRB#239). The study population consisted of patients older than 18 years of age admitted to our hospital due to fall on an outstretched hand and undergo radiological examination of the wrist with four standard radiological projections (neutral rotation posteroanterior, lateral, 45° semipronated oblique, scaphoid view with 30° wrist extension and 20° ulnar deviation) with a suspected scaphoid fracture between 2019 and 2023. Scaphoid fractures caused by high-energy trauma, patients with perilunate fracture/dislocations, patients with concomitant wrist fractures, patients younger than 18 years of age, patients with wrist fractures other than scaphoid, patients with previous wrist fractures, patients with arthritis, patients with insufficient medical data and poor-quality radiographs were excluded from the study.

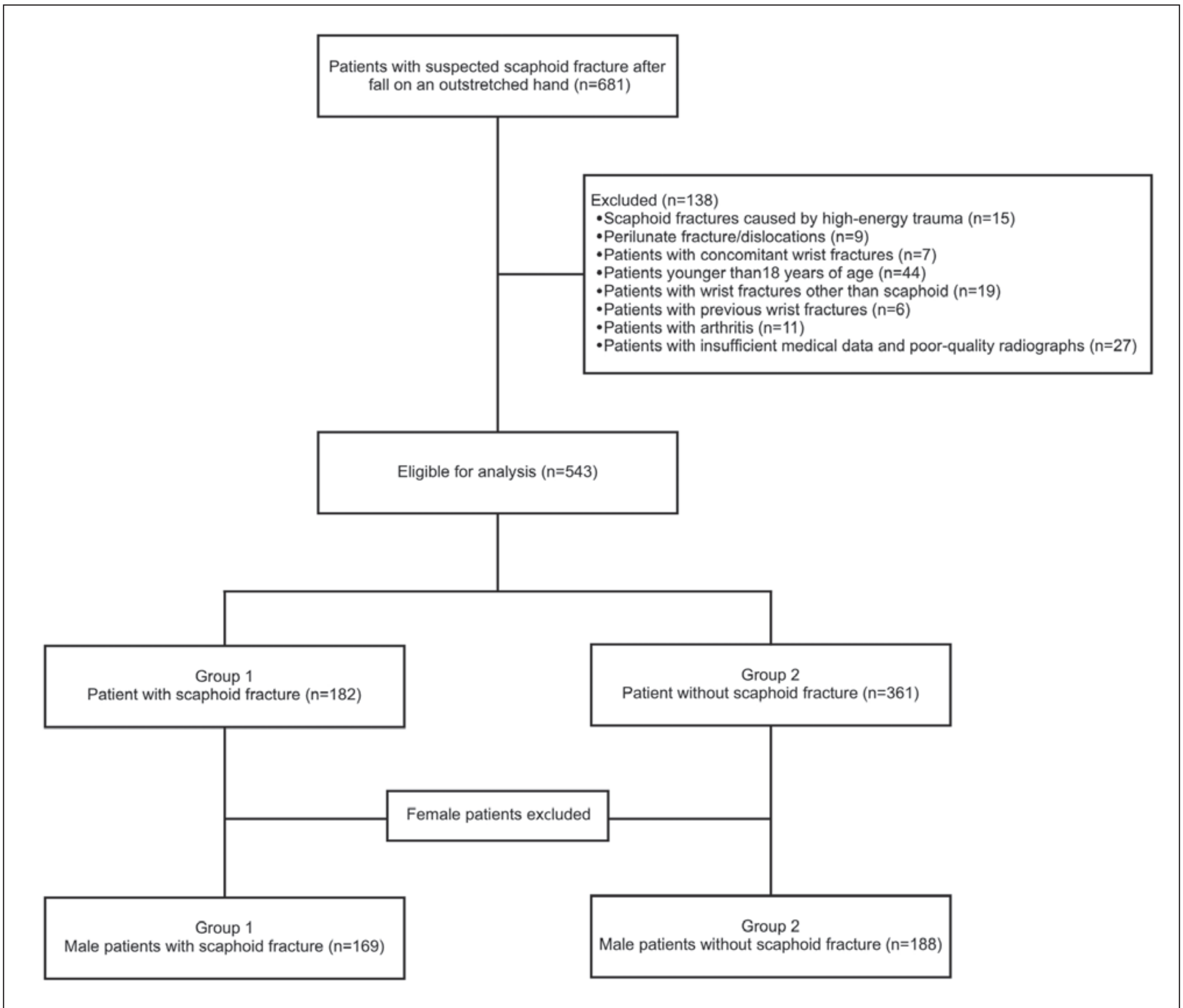


*Fig. 1. The flow diagram of the study.*

Patients were then divided into two groups according to the presence of scaphoid fracture. All available imaging studies including follow-up radiographs, computed tomography (CT) and magnetic resonance imaging (MRI) were reviewed to diagnose an occult scaphoid fracture. 182 patients with scaphoid fracture were included in Group 1 and 361 patients without scaphoid fracture were included in Group 2. Since there were 13 female patients with scaphoid fractures and to prevent gender-related factors from affecting the results, female patients were excluded from the study and the study was conducted only with male patients. After exclusion of female patients, the study was carried out with 169 patients in Group 1 and 188 patients in Group 2. The flow diagram of the study is shown in Figure 1.

### Radiological measurements

Posteroanterior (PA) and lateral digital radiographs of the injured wrists of the patients obtained from Picture archiving and Communication Systems (PACS) were used for radiologic measurements. All radiographs were taken with a single digital X-ray device (Jumong, SG HealthCare, Korea) in the emergency department. Before measurements were made, it was evaluated whether the radiographs were taken in the appropriate position. To evaluate the appropriateness of the PA radiographs, the extensor carpi ulnaris groove position recommended by Levis et al. was checked (14). Accordingly, radiographs of patients with extensor carpi ulnaris groove radial to the straight line that passes tangential to the radial edge of the ulnar styloid at the fovea were used for measurement. The appropriateness of lateral radiographs is determined by the method described by Yang et al. with evaluation of the palmar cortex of the pisiform (28). With this method, if the palmar cortex of the pisiform overlies the central third of the interval between the palmar cortices of the distal scaphoid pole and the capitate head, the lateral radiograph is considered adequate. Radiographs that did not meet these criteria were not used in the study.

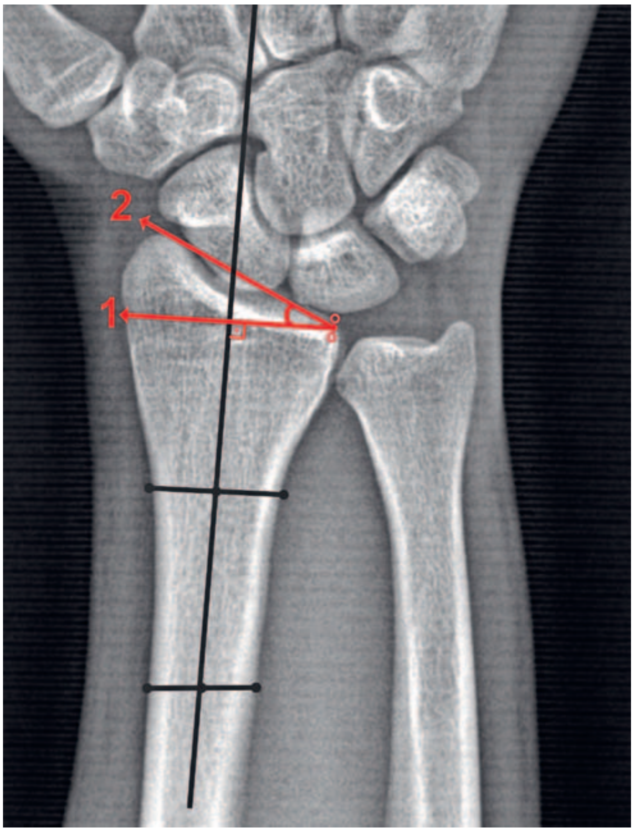


*Fig. 2. Measurement of radial inclination. Arrow 1 refers to the line drawn through the midpoint of the ulnar border of distal radius perpendicular to the longitudinal axis of the radius. Arrow 2 refers to the line that is drawn from the tip of the radial styloid process to the ulnar border of the distal radius, passing through the midpoint between the dorsal and palmar radial cortical margins. Radial inclination is measured as the degrees of angle between Arrow 1 and 2.*

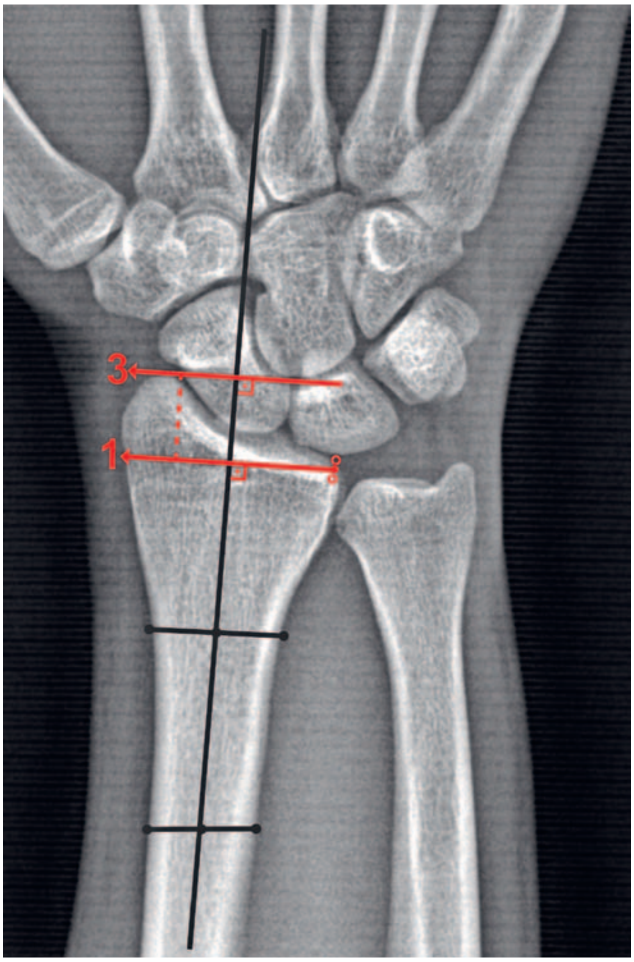


*Fig. 3. Measurement of radial height. Arrow 3 refers to the line that is drawn through radial styloid perpendicular to the longitudinal axis of the radius. Radial height is measured as distance (millimeters) between Arrow 1 and 3.*

All radiological measurements were performed together with consensus by a team including an independent orthopedic surgeon with 14 years of clinical experience and an independent radiologist with 11 years of clinical experience. All measurements were done with the digital angle and distance measurement tools in the PACS. Radial inclination (RI), radial height (RH), ulnar

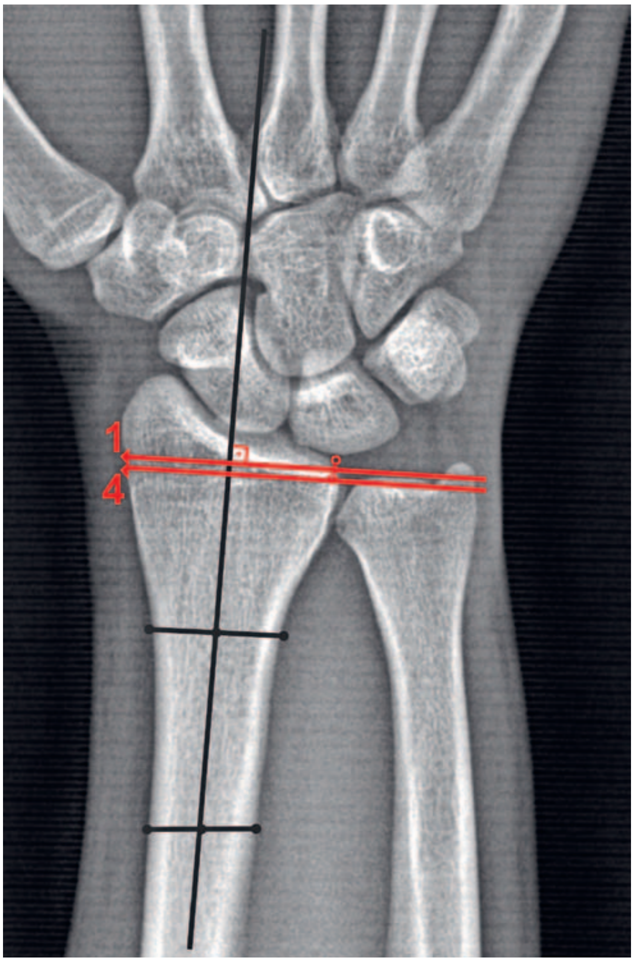


*Fig. 4. Measurement of ulnar variance. Arrow 4 refers to the line that is drawn tangent to the distal articular surface of the ulna perpendicular to the longitudinal axis of the radius. Ulnar variance is measured as distance (millimeters) between Arrow 1 and 4. A negative value is given if the distal ulnar articular surface is proximal to the Arrow 1, and a positive value is given if it is more distal to the Arrow 1.*

variance (UV), carpal height (CH) ratio and revised carpal height (RCH) ratio were measured on PA radiographs. Palmar tilt of the distal radius (PT) was measured on lateral radiographs.

For measurement of RI, first the longitudinal axis of the radius is drawn as a reference line. The second reference line is drawn from the tip of the radial styloid process to the ulnar border of the distal radius, passing through the midpoint between the dorsal and palmar radial cortical margins. RI is measured as the angle between the second reference line and a line perpendicular to the longitudinal axis of the radius (5) (Fig. 2).

RH is measured as distance between two perpendicular lines to the radial axis drawn through radial styloid and midpoint of ulnar border of the distal radius (2) (Fig. 3).

UV is measured as described by Gelberman (11). First, a line perpendicular to the radial axis is drawn through the ulnar margin of the radius. Second, a line perpendicular to the radial longitudinal axis is drawn tangent to the distal articular surface of the ulna. The distance between two lines is defined as UV (Fig. 4).

CH ratio of Youm is calculated by dividing carpal height measured in line with the third metacarpal axis as the distance from the base of the third metacarpal to


*Fig. 5. Measurement of carpal height ratio of Youm. Arrow 5 refers to the carpal height measured in line with the third metacarpal axis as the distance from the base of the third metacarpal to the distal radial articular surface. Arrow 6 refers to the length of the third metacarpal. Carpal height ratio is calculated by dividing Arrow 5 to 6.*

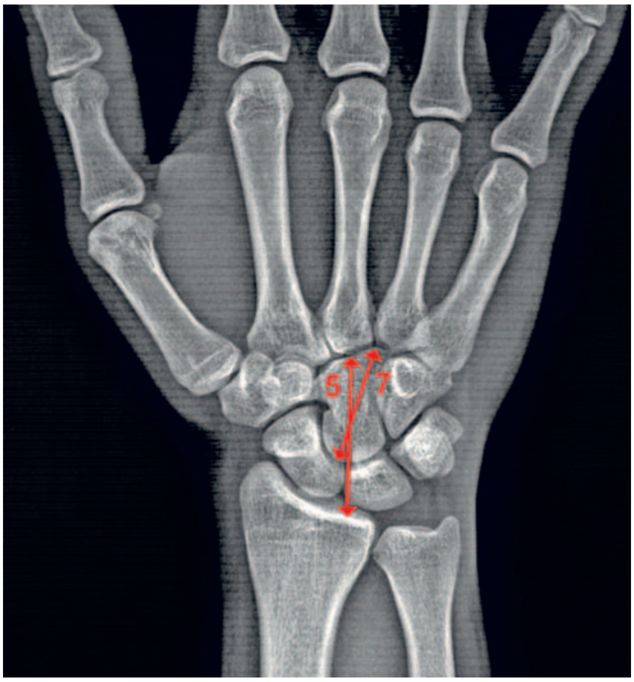


*Fig. 6. Measurement of revised carpal height ratio of Natrass. Arrow 7 refers to the length of capitate. Revised carpal height ratio of Natrass ratio is found by dividing Arrow 5 to 7.*

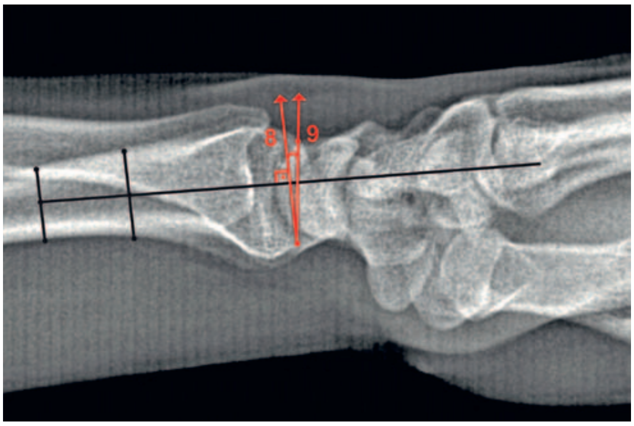


*Fig. 7. Measurement of palmar tilt. Arrow 8 refers to the line perpendicular to the longitudinal axis of the radius. Arrow 9 refers to the line tangent to the dorsal and palmar margins of the distal radius. Palmar tilt is measured as the degrees of angle between Arrow 8 and 9.*

the distal radial articular surface by the length of the third metacarpal (29) (Fig. 5).

RCH ratio of Natrass is found by dividing the carpal height to the capitate length, which is defined as the greatest distance between its distal and proximal articular surfaces (18) (Fig. 6).

PT is measured between a reference line tangent to the dorsal and palmar margins of the distal radius and a line perpendicular to the longitudinal axis of the radius (17) (Fig. 7).

## Statistical analysis

Continuous variables were presented as mean ± standard deviation, and categorical variables were presented as frequency and percentage. The Kolmogorov-Smirnov test was used to test the normality of distribution. Comparative analysis of two independent groups was performed using the Student's t-test, the Mann-Whitney U test and Chi-square test. Receiver operating characteristics (ROC) curve analysis was used to assess the diagnostic performance for each variable with statistically significant difference. The sensitivity, specificity, cutoff value, and area under the ROC curve (AUC) were analyzed. The optimal cutoff value was defined as the point that yielded the best sensitivity and specificity for the differentiation. In addition, the Odds ratio was calculated for the defined cutoff values. A value of $p < 0.05$ was accepted as statistically significant.

## RESULTS

The study was performed with a total of 357 patients, 169 patients with scaphoid fracture in Group 1 and 188 patients without scaphoid fracture in Group 2. The mean age of the patients was 29.2 ± 9.9 years in Group 1 and 31 ± 10.8 years in Group 2 (p=0.124). In Group 1, 87 (51.5%) patients had right and 82 (48.5%) patients had left side wrist injuries, and in Group 2, 89 (47.3%) patients had right and 99 (52.7%) patients had left side wrist injuries (p=0.435).

Comparative RI, RH, UV, CH ratio, RCH ratio and PT values of the two groups are presented in Table 1. The mean RI and PT degrees and RH length were statistically significantly higher, and the mean UV was lower in Group 1 compared to Group 2. No difference was determined between the groups with respect to the CH ratio and RCH ratio.

Table 2 shows the best cutoff values of radiologic parameters, odds ratios for defined cutoff values and the sensitivity and specificity of these cutoff values for the differentiation of two groups. Schematic representation of ROC curves and AUC values of variables are given in Figure 8.

## DISCUSSION

Diagnosis of the scaphoid fractures in a patient with pain in the radial aspect of the wrist after a fall on an outstretched hand is sometimes challenging and up to 30% to 40% of scaphoid fractures are not identified by a combination of clinical evaluation and plain 4-view radiographs (22). However, cast immobilization of every patient with tenderness in the anatomical snuffbox, even if the radiographs are normal, with the concern of a possible nonunion development may lead to unneces-

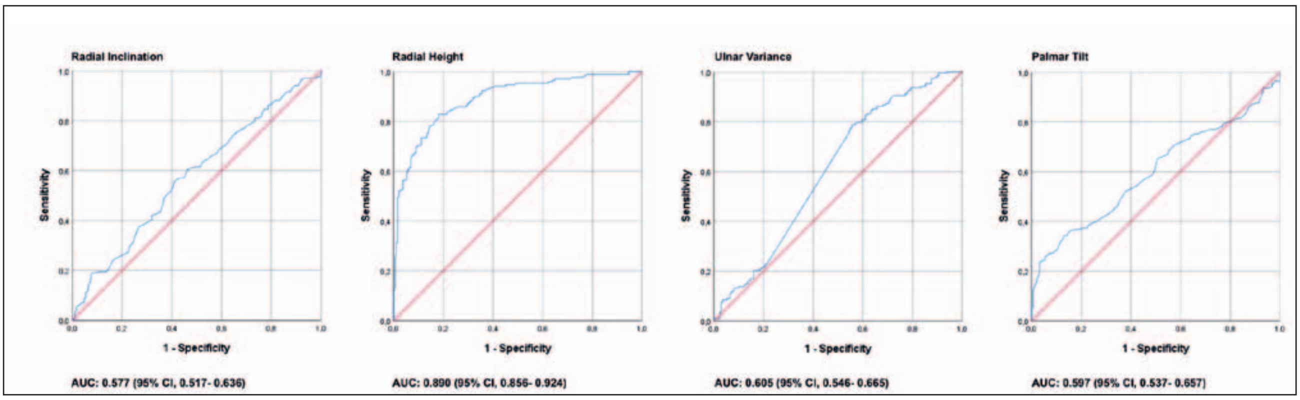


*Fig. 8. ROC curve diagrams and AUCs (95% CI) of radial inclination, radial height, ulnar variance, and palmar tilt measurements.*

*Table 1. Comparison of radiologic measurements between two groups*

| Parameter | Group 1 (n=169) | Group 2 (n=188) | p value | Test |
|---|---|---|---|---|
| Radial inclination (RI) (degrees) | 23.8 ± 2.9 | 23.1 ± 2.7 | **0.012** | U |
| Radial height (RH) (mm) | 11.9 ± 1.5 | 9.4 ± 1.4 | **< 0.001** | t |
| Ulnar variance (UV) (mm) | -0.75 ± 1.9 | 0.03 ± 1.4 | **< 0.001** | U |
| Ulnar variance category | | | **< 0.001** | $\chi^2$ |
| Negative (% within group) | 77 (45,6 %) | 46 (24.4 %) | | |
| Neutral (% within group) | 56 (33.1 %) | 99 (52.7 %) | | |
| Positive (% within group) | 36 (21.3 %) | 43 (22.9 %) | | |
| Carpal height ratio of Youm | 0.54 ± 0.02 | 0.54 ± 0.02 | 0.402 | U |
| Revised carpal height ratio of Natrass | 1.54 ± 0.07 | 1.54 ± 0.06 | 0.326 | t |
| Palmar tilt (PT) (degrees) | 12.4 ± 3.8 | 10.9 ± 2.2 | **0.002** | U |

t: Student's t-test, U: Mann-Whitney U test, $\chi^2$: Chi-square test

*Table 2. The best cutoff points for radiographic parameters for the differentiation of fractured and intact scaphoid*

| Parameter | Cutoff Value | Sensitivity (%) | Specificity (%) | Odds ratio (95% CI) | p value |
|---|---|---|---|---|---|
| Radial inclination (RI) (degrees) | 23,5 | 61 | 53 | 1.7 (1.1–2.6) | **0.01** |
| Radial height (RH) (mm) | 10.8 | 83 | 83 | 21.9 (12.7–7.7) | **< 0.001** |
| Ulnar variance (UV) (mm) | –0.83 | 78 | 45 | 2.8 (1.8–4.5) | **< 0.001** |
| Palmar tilt (PT) (degrees) | 10.8 | 65 | 50 | 1.8 (1.2–2.8) | **0.005** |

sary delayed return to work and temporary wrist stiffness (1). Considering the cost of advanced imaging, it may be the most logical approach to stratify patients with risk factors for secondary imaging.

Several studies have examined the risk factors for the need for additional radiologic examinations (6, 16, 20). In these studies, various clinical and demographic risk factors such as male gender, sports injury, loss of extension and supination strength, tenderness in the anatomical snuffbox at ulnar deviation, pain on the thumb and index finger pinch, tenderness in the scaphoid tubercle were determined. In addition to these, we think that wrist morphometric parameters may also be risk factors for scaphoid fractures. Therefore, we compared various morphologic measurements in two groups with and without scaphoid fracture. In our study, we found that RI, RH and PT values were higher and ulnar variance was lower in the group with scaphoid fracture after a fall on an outstretched hand compared to the group without fracture.

The number of studies investigating the effect of morphologic measurements on the occurrence of scaphoid fracture is limited in the literature (3, 19). In a recent study, Cohen et al. investigated morphologic risk factors for scaphoid fracture using statistical shape modeling and linear measurements and found a weak association between ulna plus and narrow radius with increased volar tilt and radial inclination wrist shape (3). They commented that adding this shape as a risk factor for the prediction rule would not be very helpful since the relationship is weak. In contrast to Cohen's study, we encountered more negative ulnar variance in the group with scaphoid fracture in our study. We think that in the presence of negative ulnar variance, the load is transferred to the scaphoid over the radial column to a greater extent during falling on the outstretched hand, and accordingly, it may constitute a risk factor for scaphoid fracture. However, when the relevant literature is examined, it is seen that there are different opinions about the effect of ulnar variance on scaphoid fracture. Cohen et al, thought that an increase in ulnar length may be a risk factor for scaphoid fractures by causing dorsal subluxation of the ulnar head during pronation, leading to decreased ulnocarpal load and increased radiocarpal load (3). Ramos-Escolona et al. found that the presence of ulna minus was a risk factor for scaphoid fracture and attributed this to the fact that the loads passing through the radial surface were higher in the case of ulna minus (19). Future comparative biomechanical studies investigating the effect of ulnar variance on radiocarpal load transfer or finite element studies comparing radiocarpal load transfers on models with ulnar variation (negative/neutral/positive) during fall on the outstretched hand will be very helpful in elucidating this controversial subject.

Another radiological parameter that has effect on the formation of scaphoid fractures is PT. Biomechanical studies show that scaphoid fractures occur with axial loading of the wrist in hyperextension above 95 degrees, in a position which the proximal pole of the scaphoid is stabilized by the tight palmar capsule and the distal part continues to extend, forming a fulcrum in the waist region (21, 25, 26). We think that the higher PT values of the scaphoid fracture group in our study may be explained by the fact that with the dorsal ridge is being more tilted, the scaphoid may be stabilized in earlier wrist extension degrees and causing the scaphoid to be prone to fracture.

One of the most striking results of our study is that RH is the most important morphometric risk factor in the formation of scaphoid fractures. ROC curve analysis of the measurement values that showed a significant difference between the two groups was performed and the cut-off values with the highest sensitivity and specificity were determined and the cut-off value with the highest odds ratio was determined as radial height (Cut-off value=10.77 mm, OR=21.886). In our opinion, the sensitivity and specificity of the cut-off values of the parameters other than RH were not high enough to be determined as a risk factor for scaphoid fractures. Increasing RH can increase the contact surface between the radial column and the scaphoid. We think that this may cause the transferred load to focus more on the scaphoid during radiocarpal load transfer. Therefore, we believe that RH is one of the most important risk factors for scaphoid fracture formation.

When the relevant literature is examined, it is seen that the effect of RH and RI on scaphoid fracture formation is not clear. Thienpont et al. found that low RI was a risk factor for scapholunate dissociation instead of scaphoid fracture (23). They commented that, with low RI the scaphoid stays in more horizontally oriented position and all the forces of torque are transferred to scapholunate ligament. In our study, RI value was found to be higher in the scaphoid fracture group. Similar to Thienport et al. we think that with an increase in RI the scaphoid may become more vertical, and accordingly, the loads may be transferred to the scaphoid bone rather than the scapholunate side during falling on the outstretched hand, which may create a risk factor for scaphoid fracture. Future studies examining the effect of RI and RH on radiocarpal load transfer may be useful to shed light on this subject.

The limitations of the current study are that it was retrospective, the sizes of groups required to demonstrate a significant difference were not calculated, and the study was conducted only with the male population. Another limitation is that although all patients were exposed to the trauma of fall on an outstretched hand, standardization is not possible as the severity of the trauma is unlikely to be the same for every patient.

## CONCLUSIONS

Although higher RI, RH, PT values and more negative ulnar variance were observed in the scaphoid fracture group compared to the non-fracture group, ROC curve analysis showed that only increased RH can be considered as a possible risk factor for scaphoid fractures after fall on an outstretched hand.

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