ORIGINAL ARTICLE

# Pros and cons of rib unfolding software: a reliability and reproducibility study on trauma patients

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## ABSTRACT

**BACKGROUND:** Examination of all 24 ribs on axial computed tomography (CT) slices might become a leeway and rib fractures (RF) may easily overlook in daily practice. Rib unfolding (RU), a computer-assisted software, that promises rapid assessment of the ribs in a two-dimensional plan, was developed to facilitate rib evaluation. We aimed to evaluate the reliability and reproducibility of RU software for RF detection on CT and to determine the accelerating effect to determine any drawback of RU application.

**METHODS:** Fifty-one patients with thoracic trauma formed the sample to be assessed by the observers. The characterization and distribution of RFs on CT images in this sample were recorded independently by the non-observers. Regarding the presence or absence of RF, CT images were assessed blindedly by two radiologists with 5 years (observer-A) and 18 years (observer-B) of experience in thoracic radiology. Each observer assessed the axial CT and RU images on different days under non-observer supervision.

**RESULTS:** A total of 113 RFs were detected in 22 patients. The mean evaluation time for the axial CT images was 146.64 s for observer-A and 119.29 s for observer-B. The mean evaluation time for RU images was 66.44 s for observer-A and 32.66 s for observer-B. A statistically significant decrease was observed between the evaluation periods of observer-A and observer-B with RU software compared to the axial CT image assessment ($p<0.001$). The inter-observer $\kappa$ value was 0.638, while the intra-observer results showed moderate ($\kappa$: 0.441) and good ($\kappa$: 0.752) reproducibility comparing the RU and axial CT assessments. Observer-A detected 47.05% non-displaced fractures, 48.93% minimally displaced (≤2 mm) fractures, and 38.77% displaced fractures on RU images ($p=0.009$). Observer-B detected 23.52% non-displaced fractures, 57.44% minimally displaced (≤2 mm) fractures, and 48.97% displaced fractures on RU images ($p=0.045$).

**CONCLUSION:** RU software accelerates fracture evaluation, while it has drawbacks including low sensitivity in fracture detection, false negativity, and underestimation of displacement.

**Keywords:** Computed tomography (D036542); computer-assisted diagnosis (D003936); rib fractures (D012253); thoracic injuries (D013898).

## INTRODUCTION

Rib fractures (RFs) occur in 10% of all traumatic injuries, making them the most common presentation of thoracic injuries.[1] RF can lead to fatal complications such as pneumothorax, hemothorax, extrapleural hematoma, pulmonary laceration, pulmonary contusion, acute vascular injury, and abdominal solid organ injury.[2] On the other hand, RF may be underestimated that it is only a reason for back pain sedated with analgesics.[3]

Computed tomography (CT) is a crucial step in the evaluation of thoracic injuries.[4] Examination of all 24 ribs on axial CT slices might become a leeway and RF may easily overlook in daily practice.[5] However, it should be kept in mind that

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RFs, which at first appear insignificant, may worsen over time if they are overlooked.[6]

Rib unfolding (RU) technique, a computer-assisted software that promises rapid assessment of the ribs in a two-dimensional plan, was developed to facilitate rib evaluation. Introduced in the early 2010s, this application is now commonly found in PACS softwares.[7,8] With RU software, it is possible to evaluate RF in addition to other focal lesions of the ribs.[9-12]

In this study, we aimed to obtain two major outputs: First, to investigate the extent to which we can rely on the RU application to evaluate RF and second, to determine the accelerating effect to determine any drawback of RU application.

## MATERIALS AND METHODS

This retrospective study was conducted in accordance with the guidelines of the Declaration of Helsinki and approval for this study was obtained from the Institutional Ethics Board (GO 19/799). The written informed consent requirement was waived by the Ethics Committee. The research and observation dates were set between September and November of 2020.

### Conceptualization and Study Population

The study population, consisting of patients who underwent thorax CT due to trauma, was randomly selected from hospital information system. The distribution of RFs for all patients, in all aspects, in this sample, was determined by two researchers (with 15 and 22 years of experience in thorax radiology) who were not participants in the intra-observer and inter-observer evaluations.

All images included in the study had no software or non-software artifacts (Fig. 1). In addition, all patients included in the study had no configurational or numerical rib abnormalities.

The general distribution of these fractures is shown in Figure 2.

### Computed Tomography Technique, Data Acquisition, and Post-processing

All CT examinations included in the study were performed in the emergency radiology unit with 64 slices CT system (Somatom Perspective 64, Siemens Healthineers®, Erlangen, Germany). The decision to perform CT was made interdisciplinary, including emergency department as well as radiology and thoracic surgery.

CT examinations performed after intravenous injection of 90–120 ml of iodinated contrast agent (300–350 mg/ml) at a flow rate of 4 ml/s, with a delay of 35 s, followed by a saline flush of 20 ml. CT acquisition parameters were as follows: Tube voltage: 120 kV, tube current determined with optimized automatic exposure control system, collimation thickness: 0.6–2 mm, tube rotation time: 0.6–2 s, and reconstructed section thickness: 2 mm.

After bone tissue reconstruction of the 2-mm thick transverse slices (60f Kernel-Siemens®), post-processing was automatically performed; reformatted RU images were obtained using a dedicated software (CT Bone Reading, Syngo. via, version VB40B, Siemens AG Healthcare®, Germany).

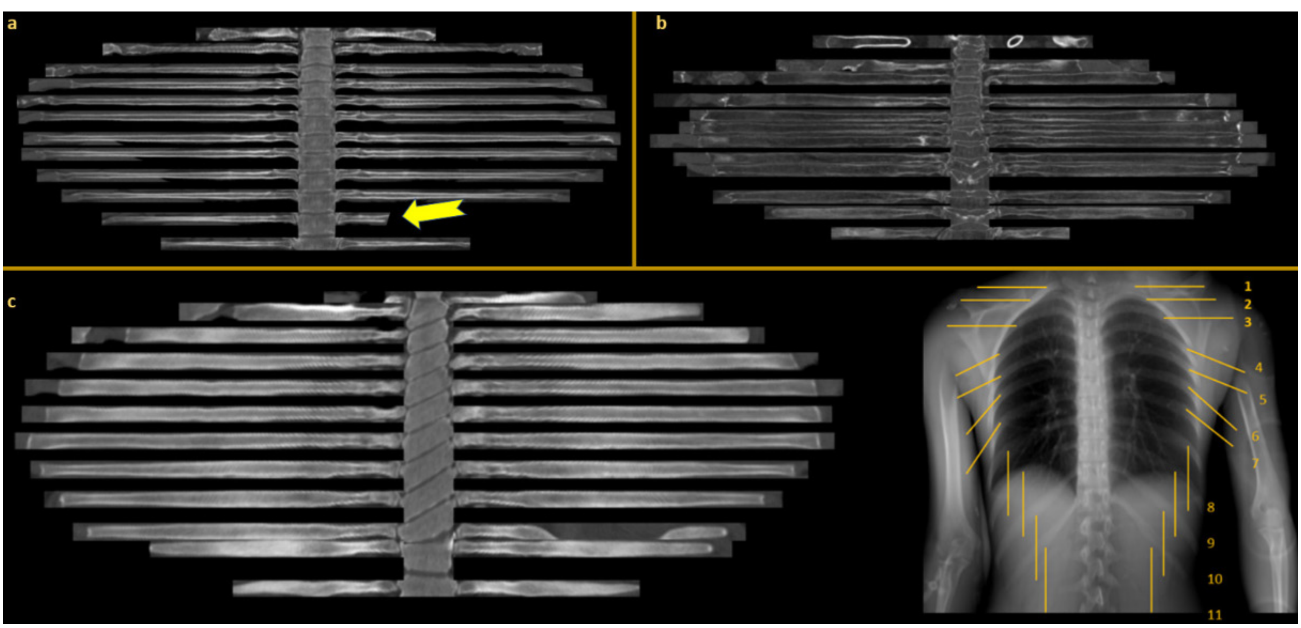


**Figure 1.** Examples of some software-related artifacts. **(a)** The rib-unfolding image demonstrates an overlooked fracture due to the displaced fracture of the 11th rib (arrow), which was manifested as a different bone by the software. **(b)** The motion artifacts cause the segmentation error in the software and result in pseudobridging of the ribs. **(c)** The rib-unfolding image reveals oblique intervertebral spaces (arrows) resulted from misinterpretation of costovertebral junctions by software in a patient with bilateral 11 ribs.


**Figure 2.** General background data on the distribution of fractures for each rib.

## Observer Evaluation

Regarding the presence or absence of RF, images blinded to patient information were independently assessed by two radiologists with 5 years (observer-A) and 18 years (observer-B) of experience in thorax radiology. Both observers were trained in the use of the CT bone reading application, which consisted of a reading session with 20 patients with RFs and normal ribs in which the axial CT images and the unfolded rib display were shown side by side.

Each observer assessed the axial slices and RU images on different days, under the supervision of non-observers who were also assigned to record both the time and the observers' results. Intra-observer testing was performed by one observer 3 months after the first evaluation.

For each evaluation, time recording began after the images were opened and prepared in the software (to avoid possible bias from the workstation hardware) and ended after determining whether or not a fracture was present, cognitively. The evaluation of RF was applied through all dimensions by rotating it 360° with the 3D spinning provided by the RU application. Decimal seconds were not recorded. After each evaluation, fractures were noted in terms of right or left side, rib number, location (proximal/middle/distal third), and degree of displacement, along with the observer's assessment time.

## Statistical Analysis

Data were summarized as mean ± standard deviations or median (range) for continuous variables, depending on the distributional properties of the data. Normality of variables was tested using the Kolmogorov–Smirnov test. Mann–Whitney U-test was used for comparison of evaluation times. Inter-observer agreement for fracture detection per patient was assessed with weighted kappa (κ) analysis. Categorical variables were evaluated with the Chi-square test or Fisher's exact test when applicable. For all tests, a two-tailed $P < 0.05$ was considered statistically significant.

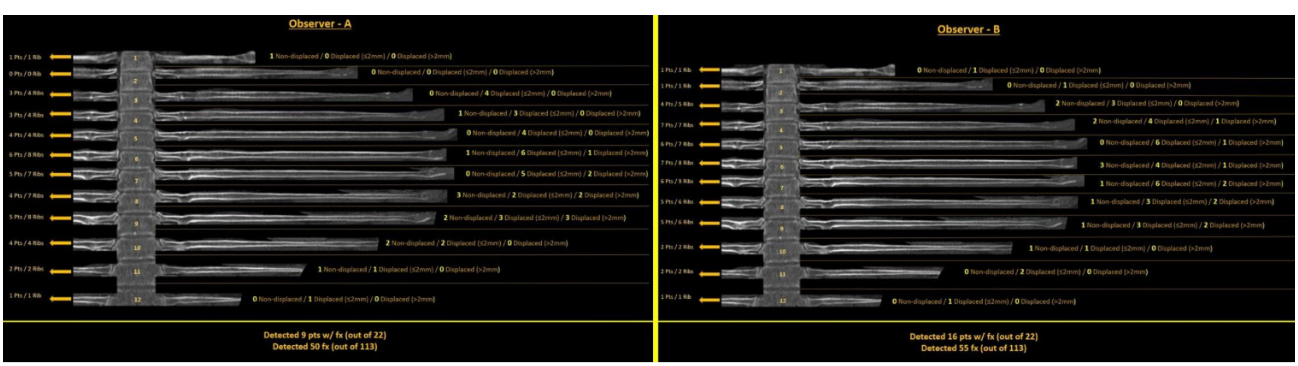


**Figure 3.** Distribution of detection and displacement by observers for each rib.

**Table 1.** Fracture and displacement detection rate with rib-unfolding technique between observers

| The Number of Existing Fractures | Observer-A† | | Observer-B† | |
|---|---|---|---|---|
| | Detection Rate | Detection Type | Detection Rate | Detection Type |
| Non-displaced (n=17) | 8 (47.05) | 7 non-displaced (87.50%) | 4 (23.52) | 3 non-displaced (75.00%) |
| | | 1 minimally displaced (≤2 mm) | | 1 minimally displaced (≤2 mm) |
| Minimally displaced (≤2 mm) (n=47) | 23 (48.93) | 19 minimally displaced (≤2 mm) (82.60%) | 27 (57.44) | 19 minimally displaced (≤2 mm) (70.37%) |
| | | 4 non-displaced | | 8 non-displaced |
| Displaced (>2 mm) (n=49) | 19 (38.77) | 8 displaced (>2 mm) (42.10%) | | 9 displaced (>2 mm) (37.50%) |
| | | 11 minimally displaced (≤2 mm) | 24 (48.97) | 15 minimally displaced (≤2 mm) |
| Total (n=113) | 44.2% (50/113) | 48.6% (55/113) | | |

†First column is the detection rate. Second column is about how the fracture displacement is observed.

## RESULTS

Overall of 51 patients (M/F=28/23), 22 had at least one RF and 113 of 1224 ribs were fractured. Of these fractures, the number of non-displaced, minimally displaced (≤2 mm), and displaced (>2 mm) fractures were 17, 47, and 49, respectively. Both observers correctly detected all fractures in axial sections. More detailed background data regarding the overall number, type, and localization of RFs are shown in Figure 2.

Observer-A detected 50 of 112 RFs (44.2%), 8 of 17 non-displaced fractures (47.05%), 23 of 47 minimally displaced (≤2 mm) fractures (48.93%), and 19 of 49 displaced (>2 mm) fractures (38.77%) using RU software (p=0.009). Observer-B detected 55 of RFs (48.6%), 4 of 17 non-displaced fractures (23.52%), 27 of 47 minimally displaced (≤2 mm) fractures (57.44%), and 24 of 49 displaced (>2 mm) fractures (48.97%) on RU images (p=0.045). The overall detection rate of both observers in detecting non-displaced, minimally displaced, and displaced fractures on RU images was 58.8%, 80.8%, and 34.6%, respectively. More detailed information about the fracture and displacement detection rate of observers is shown in Table 1, which also presents the observer determination for the displacement degree of RFs. Furthermore, the distribution of fractures detected by each observer is shown in Figure 3.

Since no false-positive observation was presented by any observer, 100% specificity and positive predictive value rates were achieved for both observers. Apart from these results, sensitivity, negative predictive value (NPV), and accuracy rates are shown in Table 2. Observer B yielded higher diagnostic performance in the detection of RFs compared to observer A.

General agreement was found for both inter-observer and intra-observer measurements (p<0.001). Intra-observer results showed moderately consistent values for observer-A (κ:

**Table 2.** Patient-based and rib-based rib fracture detection rate of observers using rib-unfolding software†

| | Patient based (%) | | Rib based (%) | |
|---|---|---|---|---|
| | Observer-A | Observer-B | Observer-A | Observer-B |
| True positive | 9 | 16 | 50 | 55 |
| True negative | 29 | 29 | 1111 | 1111 |
| False positive | 0 | 0 | 0 | 0 |
| False negative | 13 | 6 | 63 | 58 |
| NPV | 69.05 (61.17–75.95) | 82.86 (70.95–90.53) | 94.63 (93.74–95.41) | 95.04 (94.12–95.82) |
| Sensitivity | 40.91 (20.71–63.65) | 72.73 (49.78–89.72) | 44.25 (34.91–53.89) | 48.67 (39.16–58.26) |
| Accuracy | 74.51 (60.37–85.60) | 88.24 (76.13–95.56) | 94.85 (93.46–96.02) | 95.26 (93.92–96.38) |

†Values in parentheses are 95% CI. PPV: Positive predictive value; NPV: Negative predictive value, CI: Confidence interval.

**Table 3.** Inter-observer and intra-observer agreement results of rib-unfolding evaluation

| | Observer-A | Observer-B |
|---|---|---|
| Detected fracture (patient-based) | 9 | 16 |
| Missed fracture (patient-based) | 13 | 6 |
| Intra-observer agreement (κ) | 0.441 (p<0.001) | 0.752 (p<0.001) |
| Inter-observer agreement (κ) | 0.638 (p<0.001) | |

0.441), while observer B showed more consistent values (κ: 0.752). The inter-observer κ value was calculated to be 0.638. More detailed results are presented in Table 3.

The general timing data of the observers' evaluations are shown in Table 4. Mean time periods of evaluation for observer-B in both axial CT images (119.29 s) and RU images (32.66 s) were shorter than observer-A (146.64 s and 66.64 s, respectively).

## DISCUSSION

In this study, we investigated the sensitivity and specificity of RU software in the detection RF and fracture displacement estimation as well as accelerator effect and reproducibility of RU in RF evaluation by comparing axial CT images. The RU software yielded limited ability to detect RF but shortened the time of RF assessment.

The overall RF detection rate of observers in this study yielded that approximately half of the RFs on RU images may be missed, suggesting limited diagnostic performance of this technique. Although we used similar methods, we found lower sensitivity rates for both observers, in contrast to the other studies, raising suspicion about the sensitivity of the RU software. In the machine learning studies using the RU application, images were evaluated over 2D images.[13,14] However, in our study, the observers' evaluations were performed in 3D using the 360-degree rotation feature of the RU application. The specificity of RU for RFs was found as 100.0% probably due to designation of the study that excluded thorax CT studies software-related or non-software-related artifacts. However, similar studies have reported high values for specificity (ranging from 92% to 98.2%) and NPV (ranging from 95.7% to 98.62%), as in our study, which also shows consistency.[13,15,16]

For fracture detection, good inter-observer agreement (κ=0.638) was found, while intra-observer agreements were rated as good (κ=0.752 – observer-A) or moderate (κ= 0.441 – observer B). Many articles investigating inter-observer reproducibility in the literature reached similar results, ranging between 0.71 and 0.86.[13,15-17]

The detection rate of RF on RU images varied between experienced and less-experienced observers in our study. Experienced observer (observer B) detected a higher number of RF (n=55, 49.1%) on RU images compared to observer A (n=50, 44.6%). These results suggest that the overall diagnostic performance of RU software may be more enhanced when used by a more experienced radiologist. However, some results of this study point out opposite suggestions. First, the degree of displacement of the in this study RFs caused different fracture detection rates between observers. Although observer-B performed higher detection rate for minimally displaced RFs (57.44%) and displaced RFs (48.97), non-displaced fractures were detected with higher detection rate by observer-A. Second, the lower intra-observer agreement in observer-B compared to observer-A suggests that RU images may be interpreted differently in separate evaluation time periods even by experienced radiologists, which limits the diagnostic reproducibility of RU in the evaluation of RF. However, the high inter-observer agreement for RU in our study, as noted in previous studies, underlines its potential to improve the reli-

**Table 4.** Timing results of observers in assessment of rib fractures on computed tomography

| | Observer-A (less experienced) | | p | Observer-B (more experienced) | | p |
|---|---|---|---|---|---|---|
| | Axial evaluation (s) | RU evaluation (s) | | Axial evaluation (s) | RU evaluation (s) | |
| Mean† | 146.64 (95.55) | 66.64 (60.71) | <0.001 | 119.29 (66.11) | 32.66 (11.87) | <0.001 |
| Median | 113.0 | 44.0 | | 91.0 | 30.0 | |
| 95% CI | 119.77–173.52 | 49.57–83.72 | | 100.69–137.89 | 29.32–36.00 | |
| Range‡ | 485.0 (71.0–556.0) | 252.0 (16.0–268.0) | | 277.0 (68.0–345.0) | 56.0 (16.0–72.0) | |

†Values in parentheses are SD; ‡Values in parentheses are minimum and maximum timings; CI: Confidence interval; RU: Rib Unfolding; SD: Standard deviation.

ability of RU in the assessment of acute chest trauma.[13,15-17]

The RFs examined in this study were divided into non-displaced (linear), minimally displaced, and displaced fractures. The overall detection rate of the RF types showed a detection rate of 58.8%, 80.8%, and 34.6% for non-displaced, minimally displaced, and displaced RFs, respectively. These results indicate that RU images are most helpful for minimally displaced RFs and may underestimate fracture displacement on RU. To our knowledge, there is no other study in the literature that examines this extent of underestimation of fracture displacement by RU. This situation is probably caused by the flattening and continuity of the rib contours by the software, which may lead to a reduction in the distance between the displaced components of the fractured rib.

RU software reduced evaluation time for RFs. Accelerating effects of the RU program in the assessment of ribs results from two main facilities including demonstration of all ribs in a single planar image and automatic numbering of ribs that help to determine the sites of fractures.[15] Previous studies also noted the effect of RU in evaluation time of ribs for fractures. Glemser et al.[9] reported notably shorter mean time (8.83±5.8 s) for RU compared to axial CT images (43.53±22.55 s) in their forensic medicine study. The overall evaluation time of observer-B for either axial CT images or RU images was significantly lower than observer-A as expected. RU software resulted in statistically significant reduction in evaluation time for experienced and less-experienced radiologists which emphasizes the indisputable effect of RU in shortening evaluation time for RF detection apart from experience of radiologists. Longer post-processing time of RU compared to multiplanar image reformation time may be the only disadvantage of the RU software.[13]

Our study has limitations. First, more observers could have been included in the study. Second, the study could be repeated on more than one sample. Third, we did not include images with artifacts and pediatric patients in the study. Fourth, we did not compare the diagnostic efficiency of RU with multiplanar reformatted, curved planar reformatted, and volume-rendering images in RF detection. Fifth, diagnostic performance of RU was not evaluated according to rib level and RF localization (anterior, middle, or posterior part) in the fractured rib. Sixth, even if the software has a high NPV, the software experience of the observers may have a positive or negative impact on this value. Last limitation of the study results from its retrospective design. Since this was a retrospective study, standard of reference was established based on the findings of additional reading of two senior radiologists rather than clinically matching imaging findings with patient symptoms. Furthermore, no other reference standard such as scintigraphy or magnetic resonance imaging was used since these imaging techniques have no utility in acute trauma setting.

## Conclusion

Although RU yields a complete overview of the chest on a single, clear, planar image, and speeds up the assessments of RF, leading to faster detection of RFs, it also has drawbacks, including false negativity and underestimation of fracture displacement. In addition, users may need to take time to gain experience with the RU software. Axial slice examination should remain as a reliable tool for those who assess CT more professionally, such as emergency radiologists, until RU software is optimized.

**Ethics Committee Approval:** This study was approved by the Hacettepe University Medicine Faculty Clinical Research Ethics Committee (Date: 16.07.2019, Decision No: 2019/19-23

**Peer-review:** Externally peer-reviewed.

**Authorship Contributions:** Concept: A.G.E., M.R.O., İ.S.İ., B.E, EA; Design: A.G.E., M.R.O., İ.S.İ., B.E., E.A.; Supervision: A.G.E., M.R.O., İ.S.İ., B.E., E.A.; Materials: E.A.; Data: M.R.O.; Analysis: İ.S.İ.; Literature search: M.R.O.; Writing: A.G.E.; Critical revision: E.A.

**Conflict of Interest:** None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

## "Rib Unfolding" yazılımının artıları ve eksileri: Travma hastaları üzerine güvenilirlik ve tekrarlanabilirlik çalışması

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AMAÇ: Aksiyel bilgisayarlı tomografi (BT) kesitlerinde 24 kaburganın tamamının incelenmesi fazla vakit alabilmesinin yanı sıra günlük pratikte kosta kırıkları kolaylıkla gözden kaçabilir. Kostaların değerlendirmesini kolaylaştırmak amacıyla, kostaları iki boyutlu bir planda hızlı bir şekilde değerlendirilmeyi sağlayan, "Rib Unfolding" (RU) isimli bilgisayar destekli tanı koyma yazılımı geliştirilmiştir. RU yazılımını kırık tespiti için kullanmanın; güvenilirliğini, tekrarlanabilirliğini ve hızlandırıcı etkisini değerlendirmenin yanı sıra ve uygulamanın neden olabileceği sorunları belirlemeyi amaçladık.
GEREÇ VE YÖNTEM: Çalışmada gözlemci olarak görev almayacak olan araştırmacılar tarfından, göğüs travması olan 51 hastalık örneklem oluşturuldu ve örneklem içerisinde kırıkların karakterizasyonu ve dağılımı kaydedildi. Bu hastaların BT görüntüleri örneklemi oluşturan radyologlar arasında yer almayan, 5 yıllık (Gözlemci-A) ve 18 yıllık (Gözlemci-B) toraks radyolojisi deneyimleri olan, iki radyolog tarafından kırıkların varlığı, varsa tipi (nondeplase/ deplase/ minimal deplase) ve değerlendirme süreleri açısından değerlendirildi.
BULGULAR: 22 hastada toplam 113 kırık saptandı. Aksiyel BT görüntüleri için ortalama değerlendirme süresi, gözlemci-A için 146,64 saniye ve gözlemci-B için 119,29 saniye idi. RU görüntüleri için ortalama değerlendirme süresi, gözlemci-A için 66,44 saniye ve gözlemci-B için 32,66 saniye idi. RU yazılımı desteği ile gözlemci-A ve gözlemci-B'nin değerlendirme periyotları arasında; aksiyal CT görüntü değerlendirmesine göre istatistiksel olarak anlamlı azalma gözlendi ($p<0.001$). Gözlemciler arası κ değeri 0,638 iken, gözlemci içi sonuçlar RU ve aksiyel BT değerlendirmelerini karşılaştırırken orta (κ: 0,441) ve iyi (κ: 0,752) tekrarlanabilirlik gösterdi. Gözlemci-A, RU görüntülerinde %47.05 nondeplase kırık, %48.93 minimal deplase (≤2 mm) kırık ve %38.77 deplase kırık saptadı ($p=0.009$). Gözlemci-B, RU görüntülerinde %23.52 nondeplase kırık, %57.44 minimal deplase (≤2 mm) kırık ve %48.97 deplase kırık saptadı ($p=0.045$).
TARTIŞMA: RU yazılımı kırık tespitini oldukça hızlandırmakla beraber, düşük sensitivite, yalancı negatiflik ve kırığın deplasman derecesinin düşük gösterilmesi gibi dezavantajlar göstermektedir.

Anahtar sözcükler: Bilgisayar destekli tanı; bilgisayarlı tomografi; kosta kırıkları; toraks yaralanmaları.

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