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Research Article

Reliability of the figure-of-eight method for measuring foot and ankle edema: Prospective emergency department assessment and literature review

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ABSTRACT

Objective: This study aimed to evaluate the inter- and intra-rater reliability of the figure-of-eight (FoE) method for measuring foot and ankle edema when performed by emergency medicine and orthopedic residents in the emergency department (ED).

Methods: This prospective observational study was conducted at the ED of a tertiary hospital between November 2024 and January 2025. A total of 102 adult patients with foot or ankle trauma (51 males and 51 females) were included. The mean age was 38.1 ± 13.1 years. Twenty residents (10 orthopedic and 10 emergency medicine residents) performed FoE measurements. Each patient underwent eight measurements, with two repeated measurements by two raters from each specialty. The primary outcome measures were inter- and intra-rater reliability, assessed using intraclass correlation coefficients (ICC) with 95% confidence intervals, as well as the standard error of measurement (SEM) and minimal detectable change (MDC).

Results: A total of 102 patients were analyzed. Intra-rater reliability was excellent for both emergency medicine residents (ICC=0.987, 95% CI: 0.980–0.991, $P < 0.001$) and orthopedic residents (ICC=0.984, 95% CI: 0.977–0.990, $P < 0.001$). Inter-rater reliability was also excellent for emergency medicine residents (ICC=0.968, 95% CI: 0.953–0.978, $P < 0.001$), orthopedic residents (ICC=0.960, 95% CI: 0.941–0.973, $P < 0.001$), and between both specialty groups (ICC=0.951, 95% CI: 0.928–0.967, $P < 0.001$). SEM ranged from 0.57 to 1.12 cm, while MDC ranged from 1.57 to 1.75 cm for intra-rater reliability and from 2.46 to 3.10 cm for inter-rater reliability.

Conclusion: The FoE method demonstrated excellent inter- and intra-rater reliability for bedside assessment of foot and ankle edema in the emergency department. These findings support its use as a simple, inexpensive, and standardized tool for reproducible clinical assessment by both orthopedic and emergency medicine residents. The method may facilitate consistent serial evaluation of patients with acute foot and ankle trauma in routine emergency practice. Further studies are warranted to evaluate its criterion validity and responsiveness.

Level of Evidence: Level II, Diagnostic Study.

Introduction

Foot and ankle edema is a prevalent clinical issue in the emergency department (ED), arising from both traumatic events (e.g., ankle sprains, fractures) and nontraumatic causes (e.g., venous insufficiency, lymphedema).[1,2] Accurate and reproducible quantification of edema is important in the ED because it may influence clinical assessment, follow-up planning, and communication between specialties involved in patient care.[3] Since patients with ankle injuries are often evaluated by different clinicians over time, a standardized measurement method may improve consistency in serial assessment.

In clinical practice, ideal measurement tools must exhibit high inter-rater and intra-rater reliability, enable reproducible results when performed by different examiners or when repeated over time by the same examiner.[4,5] Several methods have been used to assess foot and ankle edema, including circumference measurement, water volumetry, the figure-of-eight (FoE) method, ultrasonography, and 3D optical imaging.[3,4,6-10] The FoE method stands out among these techniques due to its ease of use in clinical practice, cost-effectiveness, and suitability for treatment follow-up.[11-19] Excellent inter- and intra-rater reliability has been demonstrated in studies involving both healthy individuals and patients with edema. However, some limitations have been noted. The measurement is confined to the ankle region; measurement errors can occur due to inconsistent identification of anatomical landmarks, and the method does not evaluate the functional status of the foot or ankle.

The FoE method is also well suited to the ED because it can be performed rapidly, requires minimal equipment, and can be taught easily to residents and other healthcare providers. Although previous studies have validated the FoE method in controlled and outpatient settings,[3-18] important gaps remain, including limited data from acute traumatic ED cases, a lack of comparisons between medical specialties, uncertainty about its reliability across residents with varying experience, and the need for validation in time-pressured clinical environments.

Although the FoE method has previously shown high reliability in selected patient groups and controlled settings, evidence from ED patients with acute foot

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and ankle trauma remains limited. In addition, few studies have examined whether this method remains reproducible across different specialties involved in early trauma care. This study addresses these gaps by evaluating the FoE method in a real-world ED setting, with measurements performed by residents from 2 specialties commonly involved in ankle trauma management.

Material and methods

Study design and setting

Ethical approval for this study was obtained from the Non-Interventional Clinical Research Ethics Committee of Health Sciences University, İzmir Tepecik Training and Research Hospital (Approval number: 2024/09–12, Date: 10.10.2024). The study was conducted in accordance with the principles of the Declaration of Helsinki. This prospective observational study was conducted at the ED of İzmir Tepecik Training and Research Hospital with an annual adult admission rate of approximately 180,000, between November 1, 2024, and January 1, 2025. Written informed consent was obtained from all participants.

Study population

The study population comprised patients aged 18-65 years who were admitted to the trauma unit with ankle trauma and provided informed consent to participate. Patients were excluded if they presented with open wounds on the foot or ankle, sustained multiple traumas, were unable to complete all measurements, or could not position their ankle at 90° dorsiflexion.

Data collection

Demographic data, including age, sex, pain score, mechanism of injury (sprain injuries, blunt trauma), immobilization application in the ED, immobilization method (splint, elastic bandage), ED outcome (discharge or hospitalization), and final ED diagnoses were recorded. Pain score was evaluated using a numerical rating scale (0-10 points), where 0 indicated no pain and 10 represented the worst imaginable pain.

Measurement protocol

The FoE method protocol involves measuring the circumference around the talus and subtalar joints using a tape measure in a specific pattern resembling the number 8.[4,10,18] Measurements were performed using a non-stretchable, unmarked ribbon while the patient's ankle was positioned in 90° dorsiflexion (Figure 1). After each measurement, the ribbon was cut and stored in labeled envelopes recording the rater's identification and patient information. Upon completion of data collection, all ribbons were measured using a metric length tool, and values were recorded.

Raters

Two groups of raters participated in the study: emergency medicine residents and orthopedic residents. Each group consisted of 10 raters, determined by the number of physicians working in the ED shifts. Raters had varying levels of experience ranging from 6 to 36 months of residency training. All raters received standardized training on the FoE measurement technique prior to study initiation.

HIGHLIGHTS

- The figure-of-eight method shows excellent reliability for measuring ankle edema in the emergency department.
- Both emergency medicine and orthopedic residents demonstrated excellent intra-rater reliability.
- Inter-rater reliability was excellent within and between specialties, with minimal measurement error and detectable change.

Reliability assessment

A single-group repeated measures design was used to assess inter- and intra-rater reliability.[5] Each patient's ankle was measured by raters from both specialty groups to evaluate inter-rater reliability. Each rater performed 2 consecutive measurements to evaluate intra-rater reliability. All measurements were completed within approximately 10 minutes in order to minimize time-dependent changes in acute trauma-related edema. Measurement order was not randomized; orthopedic residents performed measurements first, followed by emergency medicine residents, primarily for logistical reasons and to ensure completion within the planned time window. Each patient's ankle was measured by 2 orthopedic residents and 2 emergency medicine residents, with each resident performing 2 measurements, resulting in 8 total measurements per patient. To reduce observer bias, an unmarked ribbon was used, raters were blinded to previous measurement values, and they were not allowed to compare their measurements with one another during the study period.

Sample size calculation

Based on a literature review showing that the intraclass correlation coefficient (ICC) of the FoE method ranges from 0.93 to 0.98, the sample size was calculated using the following parameters: a minimum acceptable reliability of 0.95, an expected reliability of 0.98, 99% power, measurement repetition count of 2, and an expected dropout rate of 15%. This yielded a required sample size of 102 patients with ankle trauma.

Statistical analysis

Statistical analyses were performed using Statistical Package for the Social Sciences for Windows, version 20.0 (IBM SPSS Corp.; Armonk, NY, USA). Qualitative data are expressed as frequency and percentage; quantitative data are expressed as mean ± standard deviation. Cronbach's alpha and ICC were used to assess inter-rater and intra-rater reliability. For inter-rater reliability, a 2-way mixed-effects model was used with absolute agreement definition for a single rater. For intra-rater reliability, a one-way random effects model was used with absolute agreement defined for a single rater.[5] All analyses were performed at a 95% CI, with $P < .05$ considered statistically significant. The ICC values were interpreted according to established guidelines: values above 0.90 indicate excellent reliability, 0.75-0.90 indicate good reliability, 0.50-0.75 indicate moderate reliability, and below 0.50 indicate poor reliability.[5] The standard error of measurement (SEM) was calculated using the formula: $SEM = SD \times \sqrt{(1 - ICC)}$ where SD is the pooled standard deviation of all measurements. The minimal detectable change (MDC) at 95% confidence level was calculated as: $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$ MDC represents the minimum amount of change that can be considered a true change beyond measurement error.

Results

A total of 102 patients were included in the study. The mean age was 38.1 ± 13.05 years, and 51 (50%) were male. The mean pain score at admission was 7.5 ± 1.0. Demographic and general characteristics of the study population are shown in Table 1. Among the patients, 66 (64.7%) sustained sprain injuries (inversion-eversion), whereas 36 (35.3%) sustained blunt trauma. Regarding ED treatment, 5 patients (4.9%) received no immobilization, 44 (43.1%) were immobilized with an elastic bandage, and 53 (52.0%) were immobilized with a splint.

Figure 1. Foot/ankle measurement using the figure-of-eight method using a non-stretchable, unmarked ribbon.

Among the 102 patients, 81 (79.4%) had no fractures associated with the trauma. Of the 21 patients (20.6%) with fractures, 9 had lateral malleolar fractures, 1 had a medial malleolar fracture, 5 had fifth metatarsal fractures, 1 had a calcaneus fracture, and 5 had phalanx fractures. A total of 101 patients (99%) were discharged from the ED, whereas 1 patient (1%) with a calcaneus fracture required hospitalization.

Inter-rater and intra-rater reliability tests were evaluated separately for orthopedic and emergency medicine residents (Table 2). All reliability coefficients demonstrated excellent values (ICC > 0.90).

Table 1. Demographic and clinical characteristics of the study population (n=102)

Age (mean ± SD)	38.1 ± 13.1
Gender: male, n (%)	51 (50.0)
Clinical presentation	
Pain score (mean ± SD)	7.5 ± 1
Mechanism of injury	
Sprain injuries (inversion-eversion) n (%)	66 (64.7)
Blunt traumas, n (%)	36 (35.3)
ED management	
No immobilization, n (%)	5 (4.9)
Elastic bandage, n (%)	44 (43.1)
Splint, n (%)	53 (52)
Disposition	
Discharged, n (%)	101(99)
Admitted, n (%)	1(1)
Radiographic Findings	
No fracture, n (%)	81 (79.4)
Fracture present, n (%)	21 (20.6)
Lateral malleolus	9 (42.9)
Medial malleolus	1 (4.8)
Fifth metatarsal	5 (23.8)
Calcaneus	1 (4.8)
Phalanx	5 (23.8)

ED, emergency department.

Discussion

This study demonstrates that the FoE method exhibits excellent inter-rater and intra-rater reliability for measuring ankle edema in the ED setting when performed by both emergency medicine and orthopedic residents. All ICC values exceeded 0.95, indicating outstanding consistency within and between raters from different medical specialties. This is clinically important because patients with acute ankle trauma are frequently assessed by different specialties during early care, whereas previous FoE studies were mostly conducted outside the ED and rarely addressed interdisciplinary reproducibility. The results suggest that the method can be applied consistently by both orthopedic and emergency medicine residents in a real-world ED setting after standardized training. Few previous studies have evaluated the reliability of ankle edema measurements; however, these studies had smaller sample sizes and fewer raters compared to the study (Table 3).

The results are consistent with previous studies evaluating the reliability of the FoE method in various clinical settings. Montoro-Cremades et al[18] reported excellent inter-rater (ICC=0.98) and intra-rater (ICC=0.93) reliability among 3 raters with varying experience levels in diabetic patients with a history of foot ulcers. Similarly, Hofmann et al[8] and Rohner-Spengler et al[3] reported ICC values above 0.98 for both inter- and intra-rater reliability in healthy and post-surgical populations, respectively. Watson et al[15] demonstrated ICC values exceeding 0.99 in patients with acute ankle sprains.

Heroes et al[17] evaluated both the water displacement and FoE methods in patients with lower limb lymphedema and healthy controls, reporting ICC values above 0.97 for both methods. Although water displacement volumetry has been considered the gold standard, the present study was designed to assess reliability rather than criterion validity. Therefore, the findings support the reproducibility of

Table 2. Intra-rater and inter-rater reliability of the figure-of-eight method

	n	Mean+SD (cm)	ICC	ICC 95% CI	*P*	SEM (cm)	MDC95 (cm)	MDC95 (%)
Inter-rater reliability								
Emergency medicine residents	102	55.29 ± 4.96	0.968	0.953-0.978	<.001	0.89	2.46	4.4
Orthopedics residents	102	55.52 ± 5.05	0.960	0.941-0.973	<.001	1.01	2.80	5.0
Orthopedic and emergency medicine residents	102	55.34 ± 5.05	0.951	0.928-0.967	<.001	1.12	3.10	5.6
Intra-rater reliability								
Emergency medicine residents	102	55.28 ± 4.90	0.987	0.980-0.991	<.001	0.57	1.57	2.8
Orthopedics residents	102	55.49 ± 5.04	0.984	0.977-0.990	<.001	0.63	1.75	3.1

ICC, intraclass correlation coefficient; MDC, minimal detectable change; SEM, standard error of measurement.

the FoE method in the ED setting but should not be interpreted as direct evidence of accuracy against a reference standard. In addition, responsiveness to clinically meaningful longitudinal change was not evaluated in the present study.

This study has several notable strengths. It features a relatively large sample size (n=102) compared to most previous reliability studies of the FoE method and includes a substantial number of raters (20 residents) from 2 different medical specialties, which enhances

Table 3. Summary of previous studies evaluating foot and ankle edema measurement methods

Author(s) and year	Participants	Study population and characteristics	Method used	Results
This study 2025	20 raters (10 emergency medicine and 10 orthopedics residents)	102 patients admitted to the emergency department with foot and/or ankle injuries	Figure-of-eight	Intra-rater eliability - Among emergency medicine residents, ICC=0.987 - Among orthopedic residents, ICC=0.984 Inter-rater reliability - Emergency medicine residents, ICC=0.968 - Orthopedic residents, ICC=0.960 - Orthopedic and emergency medicine residents, ICC=0.951
Heroes et al, [2024]	3 raters, experienced physiotherapist	Patients with lower limb lymphedema (n=47) and healthy controls (n=30)	Water displacement	Intra-rater reliability - For patient group, ICC=0.979 - For healthy control group, ICC=0.977 Inter-Rater Reliability - For patient group, ICC=0.977 - For healthy control group, ICC=0.975
			Figure-of-eight	Intra-rater reliability - For patient group, ICC=0.984 - For healthy control group, ICC=0.988 Inter-rater reliability - For patient group, ICC=0.971 - For healthy control group, ICC=0.971
Montoro-Cremades et al, 2023	3 raters in a specialized diabetic foot unit (varying levels of experience; 5 years, 1 year and none)	61 patients diagnosed with type 1 or type 2 diabetes mellitus, had a history of previous ulceration, and no active ulcers	Figure-of-eight	Intra-rater reliability, ICC=0.93 Inter-rater reliability, ICC=0.98
Hofmann et al, 2021	2 raters (the professions of the practitioners are not specified)	34 healthy volunteers	Figure-of-eight	Intra-rater and inter-rater reliability, ICC > 0.980 for all measurements
			3D optical scanning	Intra-rater and inter-rater reliability, ICC > 0.985 for all measurements
Devoogdt et al, 2019	3 raters (physiotherapists)	30 patients with primary or secondary lymphedema	Figure-of-eight	inter-rater reliability, ICC=0.94
			Water displacement	Inter-rater reliability, ICC=0.99
			Circumference measurement	Inter-rater reliability At the malleolus, ICC=0.80 At the metatarsals, ICC=0.79
Brodovicz et al, 2009	3 raters (nurse)	20 patients with type 2 diabetes and varying degrees of edema	Figure-of-eight	Inter-rater reliability Right ankle, ICC=0.64 Left ankle, ICC=0.86
			Circumference measurement	Inter-rater reliability Right ankle, ICC=0.97 Left ankle, ICC=0.97
			Water displacement	Inter-rater reliability Right ankle, ICC=0.93 Left ankle, ICC=0.96
Watson et al, 2008	4 raters (physiotherapists)	22 individuals who had acute ankle sprain and 11 uninjured (healthy) participants was included	Figure-of-eight	Intra-rater and inter-rater reliability, ICC > 0.99
Rohner-Spengler et al, 2007	3 raters (the professions of the practitioners are not specified)	30 patients who had ankle edema following surgery for malleolar fracture	Figure-of-eight (ankle angle 20°)	Measurement with skin markings Intra-rater and inter-rater reliability, ICC > 0.99 Measurement without skin markings Intra-rater and inter-rater reliability, ICC > 0.99
Mawdsley et al, 2000	2 raters (the professions of the practitioners are not specified)	15 subjects with observable ankle edema due to acute or chronic ankle sprains or lower extremity injury	Figure-of-eight	Intra-rater reliability, ICC=0.99

the generalizability of the findings. Additionally, the study was conducted in the ED setting with patients presenting acutely with traumatic injuries, thereby reflecting real-world clinical conditions. This contrasts with most previous studies that evaluated the FoE method in outpatient settings or research laboratories under more controlled conditions.

The excellent inter-rater reliability observed between emergency medicine and orthopedic residents suggests that the FoE method may support more consistent edema assessment across providers involved in early ankle trauma care.This may be particularly relevant when patients are evaluated by different specialties during the ED visit and early follow-up. From a practical perspective, the inter-rater MDC95 values of approximately 2.5-3.1 cm suggest that differences smaller than these thresholds may fall within expected measurement variability, whereas larger changes are more likely to represent a true change beyond measurement error. However, these values should not be interpreted as direct clinical decision thresholds, since responsiveness and outcome-based clinical relevance were not assessed in the present study.

Furthermore, the high intra-rater reliability (ICC > 0.98 for both groups) suggests that individual clinicians may obtain consistent repeated measurements under similar clinical conditions. However, the present study did not evaluate responsiveness to longitudinal change, and therefore these findings should not be interpreted as direct evidence of suitability for treatment-response assessment.

While water displacement volumetry has traditionally been considered the reference standard for measuring limb volume, it presents several practical limitations in the ED setting. The method requires specialized equipment, is time-consuming, and may be difficult to perform in patients with acute pain or limited mobility. Devoogdt et al[16] found that while water displacement had slightly higher reliability (ICC=0.99) compared to the FoE method (ICC=0.94), the FoE method was significantly more time-efficient. Brodovicz et al[14] reported variable inter-rater reliability for the FoE method (ICC=0.64-0.86) compared to water displacement and circumference methods. However, their study included only 3 raters and 20 patients, which may have limited the precision of reliability estimates.

Simple circumference measurements are quick and easy to perform but may not adequately capture the 3-dimensional nature of ankle edema. The FoE method provides a more comprehensive assessment by incorporating multiple anatomical landmarks and measuring circumference in a standardized pattern that encompasses the ankle joint and surrounding structures.

The study protocol standardized patient positioning (ankle at 90° dorsiflexion) and measurement technique, which likely contributed to the excellent reliability observed. The use of an unmarked ribbon may also have reduced immediate visual reading bias during bedside assessment. However, the technique remains susceptible to errors related to anatomical landmark identification, ribbon tension, placement variability, and repeated soft tissue contact. Rohner-Spengler et al[3] found minimal differences in measurement variability whether skin markings were used or not, suggesting that the method is robust even without extensive preparation. In addition, the heterogeneity of the study population should also be considered when interpreting the findings. Factors such as injury type, edema severity, fracture status, and immobilization method may influence measurement consistency, although the present study was not designed to evaluate these subgroup effects.

Limitations

This study has several limitations that should be considered when interpreting the results. First, all measurements were performed within a short time frame (10 minutes), which does not allow assessment of test-retest reliability over longer intervals when actual changes in edema might occur. This short interval was intentionally chosen to minimize time-dependent changes in acute trauma-related edema; however, repeated ribbon application over this period may have caused mild soft tissue compression or transient fluid redistribution. In addition, measurement order was not randomized, which may have introduced some systematic bias. Second, all raters were residents in training, and reliability may differ with more experienced clinicians or less experienced medical students. Third, subgroup analyses comparing reliability according to clinical presentation, such as fracture status, edema severity, or immobilization status, were not performed. Therefore, the possible influence of these factors on measurement consistency could not be evaluated. Fourth, the FoE method was not compared with other measurement techniques, such as water displacement or circumference measurements, in the same patient population; therefore, criterion validity could not be assessed. Fifth, the study was conducted at a single center, which may limit generalizability to other ED settings. Finally, the responsiveness of the FoE method to detect clinically meaningful changes in edema over time during treatment was not assessed.

In conclusion, the FoE method demonstrated excellent inter-rater and intra-rater reliability for measuring ankle edema in ED patients with acute foot and ankle trauma. These findings support the use of this simple, cost-effective, and time-efficient measurement technique for reproducible bedside clinical assessment across orthopedic and emergency medicine residents in this setting. Future studies should further evaluate criterion validity and responsiveness.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: The authors declared that no Artificial Intelligence Tool was used in the preparation of the manuscript.

Ethics Committee Approval: Ethics committee approval was received from Health Sciences University, Tepecik Training and Research Hospital (Approval number: 2024/09–12, Date: 10.10.2024).

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