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Reliability, Validity, and Feasibility of Water Displacement Method, Figure-of-Eight Method, and Circumference Measurements in Determination of Ankle and Foot Edema

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Abstract

Background: To compare interrater reliability and the time-efficiency for the water displacement method, figure-of-eight method, and circumference measurements of the ankle and foot, and to investigate concurrent validity of the figure-of-eight method and circumference measurements with the water displacement method.
Methods and Results: Thirty patients (21 women and 9 men) with primary or secondary lower limb lymphedema were evaluated twice. The volume of the foot and ankle was measured in three different ways: water displacement with a volumeter, figure-of-eight method, and circumference measurements at the level of the malleoli and metatarsals with a tapeline. The intraclass correlation coefficients (ICCs) ranged from good to excellent for all measurements (ICCs = 0.99 for water displacement; 0.94 for figure-of-eight; 0.80 and 0.79 for circumference measurement at malleolus and metatarsals). More time was needed to perform the water displacement method than the figure-of-eight method and the circumference measurements ($p < 0.001$). There was a statistically significant moderate correlation between the water displacement method and the figure-of-eight method ($r = 0.65$; $p < 0.001$), whereas the correlation coefficient between water displacement method and circumference measurements at malleolus and metatarsals was weak ($r = 0.51$, $p < 0.001$ and $r = 0.34$, $p = 0.06$, respectively).
Conclusions: Compared to the water displacement method, reliability of the figure-of-eight method is comparable, time-efficiency is better and concurrent validity is acceptable. So, in clinical practice, the figure-of-eight method is a good alternative for the water displacement method to evaluate the volume of the foot and ankle.

Keywords: lymphedema, reliability, validity, feasibility, volumeter, circumference, measurement

Introduction

Lymphedema is a chronic condition defined as an external (and/or internal) manifestation of lymphatic system insufficiency and reduced transport capacity.[1] It is due to excessive accumulation of water, filtered plasma proteins, extravascular blood cells, and parenchymal/stromal cell products in the interstitial space because of low output failure of the lymphatic system.[1–3] This mechanical insufficiency arises from a congenital lymphatic dysplasia in primary lymphedema or by the treatment of cancer, radiation, infection, or trauma leading to acquired or secondary lymphedema.[3] Whatever the pathogenesis, physical symptoms include swelling, impaired mobility, tightness, pain, and heaviness of the lymphedematous limb.[4,5] The chronic and debilitating nature of the

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lymphedema can also lead to physical and psychosocial impairments.[6,7]

In clinical settings or for research purposes, the measurement of the amount of lymphedema is necessary to determine the severity of lymphedema[8] and to evaluate the effectiveness of the treatment.[9] However, it has been reported that precision and consistency of measurement methods have to be taken into account when assessing the amount of edema.[10]

The volume of the foot and ankle can be assessed using the water displacement method by volumetry. In the literature, the water displacement method is assumed as the gold standard[11] and shown to be a valid and reliable method.[10] During this method, the limb is immersed in a container of water, the collected water overflow is weighed and this quantity represents the volume of the limb.[12] The volume of the limb can also be determined by measuring the differences of water level on a calibrated scale.[13] The water displacement method is noninvasive, inexpensive, and suitable for irregularly shaped limbs, but it requires special equipment, and it is time consuming.[14] In addition, the use of the water displacement method for patients with open wounds and in early postoperative period is not recommended.[15] For these reasons, it is not useable in clinical practice.[11,16]

In clinical practice, it has been described that circumferential measurements, including the figure-of-eight method[17] and circumference measurements with a tapeline,[10] are more practical and time efficient methods when compared to the water displacement method.[9] The figure-of-eight method was developed by Esterson,[17] and its reliability has been proposed in the measurement of foot and ankle volume in different populations, including healthy volunteers,[18,19] patients with musculoskeletal disorders,[8,9,15,19] and patients with type 2 diabetes mellitus.[10] In addition, the validity of figure-of-eight method has already been proved in the assessment of hand size in breast cancer-related lymphedema.[20]

Moreover, a simple circumference measurement with a standard tape over the malleoli or the forefoot is often used in clinical practice to assess ankle and foot girth.[19] A disadvantage of circumference measurements is that the volume of the foot cannot be measured (see details of the procedure in Measurements section). Only one study compared the reliability, feasibility, and concurrent validity of the water displacement method, figure-of-eight method, and circumference measurement at the level of ankle in patients with peripheral edema.[10] To our knowledge, there is no study examining the reliability and clinical usefulness of different measurement methods, and also reporting the correlations of figure-of-eight method and circumference measurements with the water displacement method in patients with lower limb lymphedema.

In clinical and research settings, it is important to determine more accurate, useful, and time-efficient method for the measurement of edema in patients suffering from lower limb lymphedema. For these reasons, the purpose of this study was to determine and compare the interrater reliability and the time efficiency of different measurements of the ankle and foot edema (water displacement vs. figure-of-eight vs. circumference measurements). In addition, concurrent validity of the figure-of-eight and the circumference measurements was also investigated by comparison with the water displacement, which is considered as a reference method.[10]

Materials and Methods

The study protocol was approved by the Ethics Committee of the University Hospitals of Leuven (no. B322201318781, S55894). All participants completed written informed consent.

Patients

Thirty patients were recruited, with primary or secondary lower limb lymphedema, which presents unilateral or bilateral; the diagnosis was made clinically by a lymphedema specialist. Patients who were currently receiving intensive treatment of the lymphedema with bandaging were excluded. Information concerning the type of lymphedema, type of cancer, and type of medical treatment was collected during an interview with the patient and from the medical file of the patient.

Procedure

The assessors in the present study consisted of three different physical therapists. Two of them had more than 10 years experience in evaluation of patients with lymphedema. The third therapist was less experienced, but especially trained before the start of the study. During one session, two of them were present, and each patient was evaluated by two assessors. The assessors were blinded for each other's measurements. The size of the foot and ankle was measured in three different ways as follows: the water displacement method by the volumeter, the figure-of-eight method with the tapeline, and circumference measurements at the level of the malleoli and the base of the metatarsals with the tapeline (see further for the procedure). Time efficacy was evaluated by recording the amount of elapsed time to perform each measurement.

Measurements

During the water displacement method, the volume of the foot was determined by a small volumeter (Fig. 1a). The foot was immersed slowly in a bowl of water ($34.7 \times 12.4 \times 23$), until the patient was standing on both feet. The temperature of the water was kept stable at 30°C–35°C. The overflow of water was weighted on an electronic balance and converted into milliliters.

To perform the figure-of-eight method, the patient placed the foot on a chair and held the ankle in comfortable and relaxed position (Fig. 1b). Reference points were put on the distal border of the lateral and medial malleoli and on the proximal border of metatarsal 1 and 5. Based on the standard protocol,[17] the tape was put at the middle of anterior tibial tendon and the tip of the lateral malleolus and pulled medially toward the tuberosity of navicular bone. The tape was crossed laterally the arch of the foot to the base of the fifth metatarsal. Afterward, the tape was continued to the distal border of medial malleolus via the Achilles tendon and toward the distal border of the lateral malleolus. Last, the tape was ended at the starting point. The tapeline was placed at the inner side of the reference points (Fig. 1c).

Finally, circumference measurements were performed at the distal border of the malleoli and at the proximal border of metatarsals 1–5 (Fig. 1d). The reference points were put on the same place as for the figure-of-eight method. The patient

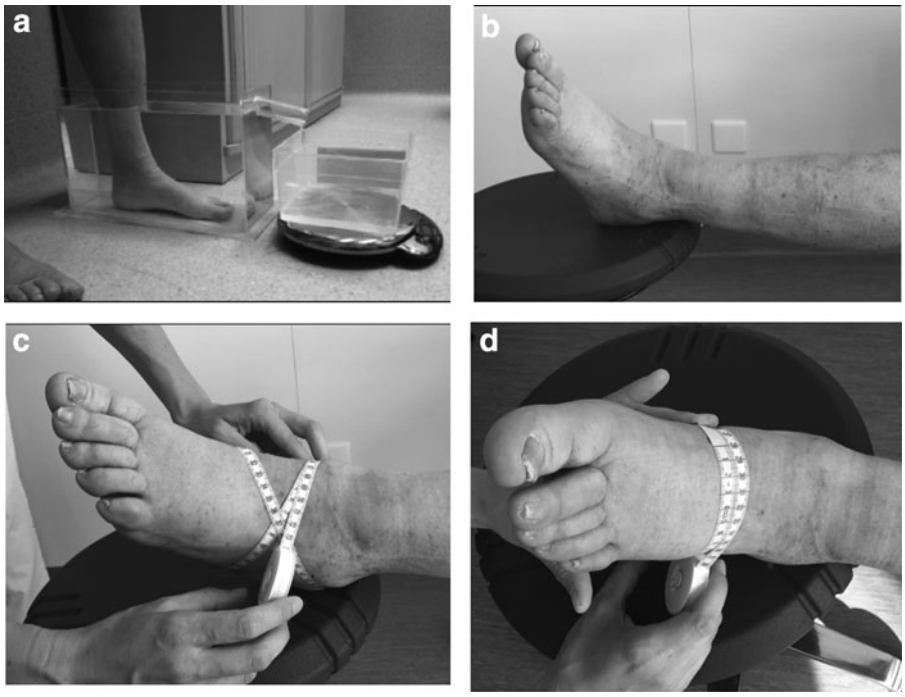

FIG. 1. **(a)** The measurement of the foot volume by using a small volumeter. **(b)** Position of the foot. **(c)** Figure-of-eight method. **(d)** Circumference measurement performed at the proximal border of metatarsals.

was sitting also in the same position as during the figure-of-eight method.

Statistical analysis

To describe the population of the study, descriptive statistics were used. Mean and standard deviations (SDs) or median and interquartile range (Q1–Q3) were determined for continuous data, while number and frequencies were computed for categorical data.

For the different measurement methods for the foot/ankle volume, the mean and SD were determined. Interrater reliability was determined with the Intraclass Correlation Coefficient (ICC). According to the guidelines offered by Portney and Watkins,[21] an ICC below 0.50 indicates poor reliability; between 0.51 and 0.75, moderate reliability; between 0.75 and 0.90, good reliability; and above 0.90, excellent reliability. To interpret the amount of error inherent in a measurement, the standard error of measurement (SEM) was calculated as $\mathrm{SEM} = \mathrm{SD}\sqrt{1-\mathrm{ICC}}$, where SD was the average SD of the 2 ratings, the SEM% was computed to indicate measurement error independent of the units of measurement as $\mathrm{SEM}\% = \% = (\mathrm{SEM}/\mathrm{mean}) \times 100$.

Time efficiency of the different measurement methods was determined with a nonparametric Friedman test. *Post hoc* analysis by using the Wilcoxon test was carried out to determine the significance between each foot measurement method. Bonferroni correction was used to adjust for multiple comparisons. The corrected p-value was calculated as <0.008.

For concurrent validity, a Pearson's coefficient correlation was computed among the water displacement method, figure-of-eight method, and circumference measurements. The data were considered normally distributed after Kolmogorov–Smirnov test had been performed. According to the guidelines offered by Portney and Watkins,[22] values between 0.00 and 0.25 indicate no or little relationship; between 0.25 and 0.50, a fair relationship; from 0.50 to 0.75, moderate to good relationship; and above 0.75 good to excellent relationship.

Results

Thirty patients participated in this study: 9 male and 21 female participants with an age of 63 ± 11 years on average. The mean body mass index was 29.8 ± 3.9 for men and 24.3 ± 7.6 for women. Thirteen patients had unilateral lymphedema and 17 of them had bilateral lymphedema. Sixteen of all the patients had a difference of less than 10% in volume between the two legs, 7 patients had a difference between 10% and 20%, and 7 patients had a difference greater than 20%. Twenty-six participants had secondary lymphedema and 22 of them had a lymphadenectomy ($n = 1$ inguinal, $n = 11$ pelvic, of whom $n = 9$ para–aortal, $n = 10$ iliacal). Two patients had stage 1 lymphedema, 17 of the participants were classified as stage 2a lymphedema, and 11 as stage 2b.

Interrater reliability

Table 1 shows the ICCs of interrater measurements, 95% confidence intervals, SEM, and SEM% of the water displacement method, the figure-of-eight method, and the circumference measurements of the malleoli and metatarsals. The water displacement method and figure-of-eight method had ICCs of 0.99 and 0.94, indicating an excellent reliability. The circumference measurement at the level of malleoli and metatarsals showed good reliability with ICCSs of 0.80 and 0.79, respectively. The SEM% was lowest for the figure-of-eight method (1.3%) when compared with the water

Table 1. Interrater Reliability of Water Displacement Method, Figure-of-Eight Method, and Circumference Measurements at Malleoli and Metatarsals

	Assessor 1, mean ± SD	*Assessor 2, mean ± SD*	*ICC*	*95% CI*	*SEM*	*SEM%*
Water displacement method (mL)	1340.6 ± 279.7	1334.9 ± 289.5	0.99	0.97–0.99	33.7	2.5
Figure-of-eight method (cm)	53.1 ± 2.8	53.6 ± 3.2	0.94	0.85–0.98	0.7	1.3
Circumference measurements (cm)						
Malleoli	27.7 ± 1.7	28.6 ± 1.9	0.80	0.14–0.94	0.8	3.0
Metatarsals	23.8 ± 1.4	24.5 ± 1.4	0.79	0.17–0.93	0.7	2.8

CI, confidence interval; ICC, intraclass correlation coefficient; SD, standard deviation; SEM, standard error of measurement.

displacement method (2.5%), circumference measurement of the malleoli (3.0%), and circumference measurement of the metatarsals (2.8%).

Time efficiency

Table 2 illustrates the significant differences in time between the water displacement method, figure-of-eight method, and the circumference measurements ($p < 0.001$). *Post hoc* analysis revealed that more time was needed for the water displacement method (3.13 ± 1.07 minutes) than the figure-of-eight method (1.03 ± 0.31 minutes; $p < 0.001$) and circumference measurements (1.03 ± 0.53 minutes; $p < 0.001$). However, there was no significant difference ($p = 0.90$) in the time needed for the figure-of-eight method and the circumference measurements.

Concurrent validity

There was a statistically significant moderate relationship between the water displacement method and the figure-of-eight method ($r = 0.65$; $p < 0.001$) (Table 3). The circumference measurement of malleoli had a lower correlation with water displacement method ($r = 0.51$; $p = 0.004$), while there was no statistically significant correlation between the water displacement method and the circumference measurement of the metatarsals ($r = 0.34$; $p = 0.06$) (Table 3).

Discussion

On the basis of the literature and our knowledge, this is the first study comparing reliability of three different methods, that is, the water displacement method, figure-of-eight method, and circumference measurements at malleoli and metatarsals to determine the size and volume of the foot and ankle in patients with lower limb lymphedema. In addition, the time efficiency of these different methods and concurrent validity between the gold standard and the other methods were investigated.

In the present study, interrater reliability was excellent and comparable for the water displacement method (ICC = 0.99) and the figure-of-eight method (ICC = 0.94), and was good for the circumference measurements (ICCs = 0.80 and 0.79).

Similar to the current study, Brodovicz et al.[10] compared the water displacement method with figure-of-eight method and circumference measurements for the measurement of edema, but this study was not performed in patients with lymphedema, in which it is often difficult to determine the reference points. Moreover, circumference measurement of the ankle was performed at a different location, 7 cm proximal of the midpoint of the medial malleolus. They reported that the water displacement method and circumference measurement of the ankle had an excellent interrater reliability with the ICCs ranging from 0.97 to 0.93.[10] However, the interrater reliability for figure-of-eight method was found lower, and there was also an inconsistency between the ICCs of left and right extremity (0.86 and 0.64, respectively). According to the authors, this difference was probably related to the dominant handedness of the assessors.[10] In the present study, only one foot with the highest lymphedema volume was evaluated.

Similar to the present study, Petersen et al.[8] also revealed that water displacement and figure-of-eight methods had excellent interrater reliability (ICCs = 0.99 and 0.98, respectively) in patients with ankle swelling due to different musculoskeletal disorders as well as pregnancy. In addition, Tatro-Adams et al.[19] reported excellent interrater and intrarater reliability with the ICC of 0.99 for figure-of-eight method in healthy volunteers. Mawdsley et al.[9] determined intrarater reliability of the figure-of-eight method as excellent (ICC = 0.99) in individuals with ankle sprain or musculoskeletal injuries. In their study, ankle joint was placed in a neutral position for the measurement for the figure-of-eight

Table 2. Comparisons of Time Efficacy Between Water Displacement Method, Figure-of-Eight Method, and Circumference Measurements

	Water displacement	*Figure-of-eight*	*Circumference measurements*	p^1	p^2	p^3
Duration of measurement (minutes)	3.0 (2.0–4.0)	1.0 (1.0–1.0)	1.0 (0.75–1.0)	<0.001*	0.90	<0.001*

Data were presented as median (25%–75%). p^1: *Post hoc* comparisons between water displacement method and the figure-of-eight method; p^2: *Post hoc* comparisons between figure-of-eight method and circumference measurements; p^3: *Post hoc* comparisons between water displacement and circumference measurements.

*$p < 0.008$; corrected p-value obtained from Wilcoxon test.

Table 3. Correlations for Water Displacement Method, Figure-of-Eight Method, and Circumference Measurements

	Figure-of-eight	*Circumference measurement at malleoli*	*Circumference measurement at metatarsals*
Water displacement	$r=0.65$ $p<0.001$	$r=0.51$ $p<0.001$	$r=0.34$ $p=0.06$
Figure-of-eight	—	$r=0.82$ $p<0.001$	$r=0.81$ $p<0.001$
Circumference measurement at malleoli	—	—	$r=0.61$ $p<0.001$

r Values were obtained from Pearson's correlation test.

measurement.[9] However, it has been reported that it is difficult to maintain the neutral position for patients with ankle swelling due to musculoskeletal injury.[15] Based on the previous study by Petersen et al.,[8] the ankle joint was placed in a comfortable position in the current study.

The results demonstrated that the figure-of-eight method had the lowest error of measurement when compared to the water displacement method and circumference measurements. Similar to our study, previous studies[9,19] found a small SEM of 0.7 and 0.4 cm for the figure-of-eight method.

Based on the results of the current study, we can state that the figure-of-eight is a fast and reliable way to evaluate the lymphedema of the foot, as well as the circumference measurements of the malleoli and metatarsals. The average time needed for the figure-of-eight method (1 minute) and circumference measurements (1 minute) was significantly lower than that one needed for the water displacement method (>3 minutes). Brodovicz et al.[10] reported that the average time for the ankle circumference was just 1 minute, for the figure-of-eight was 2.7 minutes and for the water displacement was 8 minutes (excluding set-up time); moreover, there was no difference between the three examiners.[10] The reason for increased assessment duration for figure-of-eight and water displacement can be related to the measurement of both extremities.[10]

Considering the lymphedematous foot and ankle, there was a statistically significant and good correlation between water displacement and the figure-of-eight ($r=0.65$). The correlation between water displacement and the circumference measurement of the malleolus ($r=0.51$) was higher than between water displacement and the circumference measurement of metatarsals ($r=0.34$; $p>0.05$). In the current study, it is shown that the figure-of-eight is more valid than circumference measurements in the assessment of the lymphedematous foot and ankle. When compared to the current study, Mawdsley et al.[9] found greater correlation coefficients ($r=0.90$) between figure-of-eight and water displacement methods in individuals with ankle swelling due to musculoskeletal disorder. In healthy volunteers, Henschke et al.[18] also demonstrated that water displacement and figure-of-eight methods had excellent correlations in three postural conditions, including supine ($r=0.92$), sitting without cuff ($r=0.93$), and sitting with a cuff around thigh and lower leg ($r=0.94$). In the present study, lower correlation rates can be related to the level of edema. In patients with lymphedema, the swelling can be at the level of the toes, dorsum of the foot, and ankle, and in patients with musculoskeletal edema, swelling is present at the level of the ankle.

Study limitations and strengths

The present study has some limitations. Healthy persons were not included in the study, thus these results cannot be used for healthy people. The patients were only measured at one time point, thus we had no idea of the smallest real difference. The time was recorded before and after the assessment and accurate to a half of a minute, but it would be better if a chronometer was used to determine the duration of the assessment more accurately. The chronometer is more precise, because a smaller change in time would be detectable. Finally, the area of swelling is a potential limitation that may affect the validity of the figure-of-eight method since lymphedema may be present in different parts of foot and ankle. Therefore, a further study is required to investigate the sensitivity of the figure-of-eight method in the detection of the area of swelling.

Our study has also several strengths. First, the study included patients with lymphedema with a wide range of edema volume. In addition, the different types and stages of lymphedema were represented in our study population. This makes that our sample is representative for all patients with lower limb lymphedema. Second, the measurements were performed in the same setting as in the clinical practice (there was a time limitation).

Clinical implications

In accordance with the findings of the current study, the figure-of-eight method is a reliable, valid, and time efficient alternative for the water displacement method to evaluate the size of the foot and ankle in patients with lymphedema of the foot with skin alterations.

We suggest performing the figure-of-eight method in the comfortable position of the ankle joint with a tension-controlled measuring tape. Before the execution of the figure-of-eight method, reference points have to be marked by palpation. However, in patients with severe edema of the foot and ankle, the palpation of the reference points is difficult. Therefore, clinicians and researchers always should perform the palpation of the distal border of the malleoli form distally (the heel) to proximally. The same method should be used for the palpation of the metatarsals. The palpation of the proximal border of metatarsal I and V should be applied from distally (at the medial or lateral part of the dorsum of the foot) to proximally. Finally, we suggest that during the application, the tape should not be pulled to avoid the compression of the soft tissue.

In conclusion, the water displacement method is a time-consuming and cumbersome method to evaluate the volume of the foot and ankle. Compared to the water displacement method, reliability of the figure-of-eight method is equal, time efficiency is better, and concurrent validity is acceptable. So, in clinical practice, the figure-of-eight method is a good alternative for the water displacement method to evaluate the volume of the foot and ankle.

Author Disclosure Statement

No competing financial interests exist.

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