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What is the best method to determine excessive arm volume in patients with breast cancer–related lymphoedema in clinical practice? Reliability, time efficiency and clinical feasibility of five different methods

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Abstract

Objective: To investigate the reliability, time efficiency and clinical feasibility of five commonly used methods for assessing excessive arm volume in patients with breast cancer–related lymphoedema (BCRL).
Design: Cross-sectional study.
Setting: University Hospitals Leuven, Belgium.
Subjects: 30 participants with unilateral BCRL.
Methods: Excessive arm volume was determined by five different methods: traditional volumetry with overflow, volumetry without overflow, inverse volumetry, optoelectronic volumetry and calculated volume based on circumference measurements. To investigate intra- and inter-rater reliability, measurements were performed twice by the same assessor and once by a different assessor. Intraclass correlation coefficients (ICCs), standard errors of the measurement (SEMs) and systematic changes between the

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means were calculated. To determine time efficiency, the mean setup time, execution time and total time were examined for each method. Furthermore, 12 limitations regarding clinical feasibility were listed and scored for each method. Finally, an overall ranking score was determined between the methods.

Results: Mean age was 65 (±8) years and mean body mass index was 28 (±4) kg/m^2. Intra- and inter-rater reliability ranged between strong and very strong. Calculated arm volume based on circumferences (mean excessive arm volume: assessor A: 477 (±367) mL; assessor B: 470 (±367) mL; assessor A (second time): 493 (±362) mL) showed the highest intra- and inter-rater ICCs of .987 and .984, respectively. Optoelectronic volumetry was the fastest method, representing a mean total time of 1 minute and 43 (±26) seconds for performing a bilateral measurement. The least limitations were reported on the calculated volume based on the circumference method (3 out of 12 limitations).

Conclusion: Calculated volume based on arm circumferences is the best measurement method for evaluating excessive arm volume over time in terms of reliability, low error rate, low cost, few limitations and the time spent.

Keywords

Breast neoplasms, lymphoedema, assessment, reliability, time efficiency, feasibility

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Introduction

More than 16% of the women treated for breast cancer develop lymphoedema of the arm.[1] The evaluation of the treatment effect in both research and clinical practice is not possible without an accurate, valid and reliable method to determine arm size. Especially in clinical practice, it is crucial that this measurement tool is easy to use and rapid as well.[2,3]

To date, a plethora of different measurement methods capable of determining arm size are available, such as several methods for water displacement,[4–6] optoelectronic volumetry[7] and circumference measurements.[8] The traditional way of performing the water displacement method is to measure the overflow of water.[6] An alternative method for determining the arm volume is to measure the shortness of water, called inverse water volumetry.[4] Furthermore, recently a volumetry method that does not make use of an overflow, named ValGrado by the developers,[9] has been introduced and will be further referred to as volumetry without overflow. Optoelectronic volumetry, or perometry, is another valid measurement tool that proved to be accurate and reproducible in homogeneous geometric shapes.[10] In addition, based on circumference measurements of the arm, the total arm volume can be calculated using geometric formulas, such as the truncated cone formula.[11] Supplemental Table 1 provides an overview of evidence found in the literature with regard to reliability, time efficiency and reported limitations of five commonly used measurement methods. All methods show good to very good intra- and inter-rater reliability for measuring arm volume. However, almost none of the studies report on reliability of the assessment of excessive arm volume. In addition, only a few studies also investigated the measurement error of each method. Regarding time efficiency, standardized studies investigating the time needed to perform a certain measurement are lacking. A recent systematic review providing best evidence regarding which measurement method is most appropriate in measuring lymphoedema concluded that information on feasibility is scarce.[12] A literature search regarding reported limitations of each of the methods resulted in nine possible limitations (see Supplemental Table 1).

In conclusion, although plenty of research is already published concerning reliability of different measurement methods separately, a clear overview and comparison of their utility (in terms of reliability, time efficiency and clinical feasibility), between different variants of water displacement

methods, optoelectronic volumetry and calculated volume using a perimeter, is still missing.

Therefore, the aim of this study was to investigate and compare the reliability, time efficiency and clinical feasibility of five different and commonly used methods for determining excessive arm volume in patients with breast cancer–related lymphoedema (BCRL) in clinical practice.

Methods

This cross-sectional study is part of the EFforT-BCRL trial[13] for which approval was obtained by the Ethical Committee of the University Hospitals Leuven (CME reference S58689, EudraCT 2015-004822-33, Clinicaltrials.gov NCT02609724). The study was conducted in accordance with the Declaration of Helsinki and is reported following the recommended STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guidelines for observational studies.

Participants

Between July and November 2017, participants of the EFforT-BCRL trial were asked to contribute in this subtrial. Eligibility criteria were as follows: (1) female/male patients with unilateral BCRL of the arm, (2) currently in the maintenance phase of the decongestive lymphatic therapy and (3) no known recurrence of cancer. Participants were excluded when they (1) had solely hand oedema and (2) had open skin lesions on one of their arms at the time of testing. All the participants received written and oral information by mail as well as by phone. All the participants signed the informed consent document in the prior EFforT-BCRL trial.

Data collection and assessments

All assessments were performed at the Department of Physical Medicine and Rehabilitation of the University Hospitals Leuven. Excessive arm volume of all participants was determined by five different methods:

- Traditional volumetry with overflow, in which the overflow of water is weighed;[6]
- Volumetry without overflow, in which the volume of the upward displaced water is weighed when submerging the limb in the recipient;[9]
- Inverse water volumetry, an alternative method for determining arm volume whereby the shortness of water is measured;[4]
- Optoelectronic volumetry (or perometry), a method that makes use of an optoelectronic infrared device to detect volume differences (without considering hand volume);[10]
- Calculated volume based on circumference measurements, whereby the total arm volume (without considering hand volume) can be calculated using geometric formulas, such as the truncated cone formula.[11] This formula postulates that every section of the limb represents a perfect circle and that the walls of the cone are rectilinear.

For each participant, the volume of both arms was measured. To determine the excessive arm volume, the volume of the non-oedematous arm was subtracted by the volume of the oedematous arm. Supplemental Table 2 comprises a detailed overview of the five different measurement methods for assessing arm volume and excessive volume and their standardized procedures.

Descriptive data were collected by interviewing the participants and by consulting their medical records. For each participant, only one visit to the hospital was necessary to collect all data. Participants arrived 15 minutes prior to the start of the measurements at the hospital in order to stabilize skin temperature with room temperature.[14] In our study room, a constant temperature of 21°C was maintained. During this time, compression sleeves and jewellery on both arms were removed.

The estimated duration for a single execution of the five different measurements was 30 minutes (i.e. one assessment block). Since the execution of an assessment block was performed three times consecutively, the total duration of the investigation was approximately 1.5 hours per participant. The sequence of the five measurement methods in one assessment block varied between the different participants; however, within each participant, the same sequence was maintained among the three executions. The order of the measured sides during

the measurements was chosen randomly. Prior to the assessments, three different 2-hour training moments were scheduled to guarantee standardization between assessors (T.D.V., L.V.), as well as three consecutive 1-hour training moments focused on time measurements between the persons registering the scores (S.V.D.S., A.V.H., M.B., T.P.).

To investigate intra-rater reliability, the first and the last assessment block were performed by the same assessor (T.D.V.). To investigate inter-rater reliability, the second one was performed by a different assessor (L.V.). In order to obtain blinding of the assessors for previous test results, a different person registered the score. To preserve blinding for the reference point(s), after completing each assessment block consisting of the five methods, reference points were removed using alcohol wipes.

To provide an overview concerning time efficiency of the five methods, a subdivision was made between (1) the time needed to prepare the measurement, which is reported as setup time, (2) the time needed for a bilateral execution of the measurement, which is reported as execution time, and (3) the total time required for the setup and execution of the measurement.

The setup of the measurement equipment was consistently prepared according to a predetermined and standardized protocol. Volumeters were filled with tepid water since it was shown in the literature that water temperatures across this range do not affect the density of water (and consequently the weight of water measured) and do not cause vasodilatation/vasoconstriction of the blood capillary system.[6,15,16] The setup time was determined for traditional volumetry with overflow, volumetry without overflow and inverse volumetry. Other methods did not require any preparation in advance (Supplemental Table 2). Subsequently, execution of the five different methods was timed in a consistent and standardized manner as well. In Supplemental Table 2, the timing protocol for each method in particular is described in more detail.

Limitations regarding clinical feasibility of the different methods reported in the literature (Supplemental Table 1) were discussed by a team of experts in the field. In addition, limitations reported by the experts retrieved from clinical experience were added to the list, after which all limitations were scored for each of the five measurement methods (yes/no). Two experts have many years of clinical and scientific experience in using the measurement methods (N.D., N.G.), and the other expert has performed the assessments during this study (T.D.V.).

Finally, an overall comparison between the five methods regarding their reliability, time efficiency and clinical feasibility is performed in order to provide an overview of the most appropriate method to use in clinical practice for measuring the excessive arm volume over time.

Data analysis

Statistical analyses were performed using IBM SPSS Statistics (SPSS Inc., Chicago, IL, USA) for Windows version 24.0. The .05 level of significance was applied. Descriptive statistics for continuous values are presented as mean ± SD for normal distributed data and median and interquartile range for not-normal distributed data. Categorical variables are presented as number and proportion (%).

Reliability of the volume measurements of the oedematous limb, the non-oedematous limb and the excessive arm volume were analysed. Intraclass correlation coefficients (ICCs) were used to examine intra- and inter-rater reliability between the different measurement occasions.[17] ICC estimates and their 95% confident intervals (CIs) were calculated based on a single rating ($k=1$), absolute agreement and two-way random-effects model.[18,19] The ICCs were interpreted as follows: $<.40$ weak, .40 to .74 as moderate, .75 to .90 as strong and $>.90$ very strong.[20,21]

To interpret the magnitude of the within-subject variation of the two scores, the standard error of measurement (SEM) was calculated using the following formula: $SEM = SD(difference)/(2)^{0.5}$, where SD was the standard deviation of the volume differences between the two assessments.

To calculate systematic changes in the mean between two measurement occasions, paired-samples *t*-tests were applied since the Shapiro–Wilk test revealed a mainly normal distribution of data.

A one-way analysis of variance (ANOVA) was executed to demonstrate statistically significant differences among group means, assisted with post hoc analyses for further evaluation.

Descriptive statistics on the reported limitations were performed to describe the clinical feasibility of each method.

Finally, data were used to compile a ranking table. Therefore, reliability of each method was based on the intra- and inter-rater ICC values of the excessive volume and was ranked between 1 (the most reliable method) and 5 (the least reliable method). The rating of time efficiency was based on the total time and consequently resulted in a ranking between 1 (the most time-efficient method) and 5 (the least time-efficient method). The rating of clinical feasibility was determined as the sum of scores on the reported limitations for each method. Based on this score, all methods were ranked between 1 (the most feasible method) and 5 (the least feasible method). Finally, based on the sum of the different scores on each item, the methods were ranked between 1 (the most appropriate method) and 5 (the least appropriate method).

Results

A total of 30 women were enrolled in this study. All measurements were completed in all 30 participants. Mean age was 65 (±8) years and mean body mass index (BMI) was 28 (±4) kg/m^2. An overview of the characteristics of the included subjects is provided in Table 1.

Supplemental Table 3 and Table 2 list the intra and inter-rater ICC values (with 95% confidence interval (CI)), the SEMs (with 95% CI) and the mean volumes on each test occasion, supported with the outcomes of the paired-samples *t*-tests.

Table 1. Characteristics of the included subjects ($n = 30$).

Variable	Outcome, mean (SD)
Descriptives	
Age (years)	65 (8)
Body mass index (kg/m^2)	28 (4)
Duration of lymphoedema (months)	74 (44)
Variable	**Outcome, *N* (%)**
Frequencies	
Lymphoedema stage	
Stage I	3 (10)
Stage IIa	18 (60)
Stage IIb	9 (30)
Location of lymphoedema	
Lower arm	14 (53)
Upper arm	0 (0)
Total arm (lower arm + upper arm)	16 (47)
Breast surgery	
Mastectomy	21 (70)
Breast-conserving surgery	9 (30)
Axillary lymph node clearance	
SLNB	1 (3)
ALND	29 (97)
Surgery on the dominant side	17 (57)
Radiotherapy	30 (100)
Chemotherapy	24 (80)
Antihormonal therapy	27 (90)
Target therapy (Herceptin)	6 (20)

SLNB: sentinel lymph node biopsy; ALND: axillary lymph node dissection.
Lymphoedema stages as described by the International Society of Lymphology (i.e. Stage I = Accumulation of interstitial fluid, with reduction by elevation. At this stage, the oedema can be pitting. Stage IIa = Swelling disappears barely by elevation, the oedema is clearly pitting. Stage IIb = Pitting is clearly present by fibrotic formations in the oedema).

Intra-rater reliability

Taking into account the results considering the excessive arm volume, all the methods showed satisfying ICCs, ranging from .777 to .987. The calculated arm volume based on circumferences showed the highest ICC of .987. Similar to the ICC results, the calculated arm volume based on circumferences showed the lowest SEM, resulting in a variation of 41.58 mL from one test occasion to the other.

Inter-rater reliability

Likewise, considering the results regarding the excessive volume between the two arms, ICCs

Table 2. Inter-rater reliability (n = 30).

	Method	First assessment (assessor A), mean volume (SD; min, max)	Second assessment (assessor B), mean volume (SD; min, max)	ICC (95% CI)	SEM (95% CI)	*P*-value (paired-samples *t*-test)
Oedematous limb	Traditional volumetry with overflow	2662.64 (384.63; 1692.4, 4401.3)	2647.33 (708.74; 1596.4, 4436.1)	.954 (.907, .978)	117.25 (–245.50, 214.12)	.694
	Volumetry without overflow	2253.21 (515.69; 1463.1, 4401.3)	2228.16 (488.66; 1149.6, 2901.4)	.980 (.957, .990)	71.02 (–114.15, 164.25)	.452
	Inversed volumetry	3160.4 (653.85; 2033, 4760)	3195.97 (692.24; 1934, 4632)	.974 (.947, .988)	108.53 (–177.14, 248.28)	.206
	Optoelectronic volumetry	5245.47 (747.32; 4140, 7048)	5062.07 (720.13; 4081, 6676)	.949 (.504, .986)	165.70 (–141.37, 508.17)	<.001**
	Calculated arm volume based on circumferences	3000.88 (764.12; 1911.9, 4727.6)	2942.47 (732.58; 1861.4, 4608.4)	.993 (.921, .998)	62.61 (–56.31, 189.13)	<.001**
Non-oedematous limb	Traditional volumetry with overflow	2180.99 (534.31; 1337.5, 3720.6)	2148.99 (525.8; 1370.7, 3686.9)	.984 (.964,.992)	67.05 (–99.41, 163.41)	.068
	Volumetry without overflow	1816.66 (332.32; 1193.0, 2623.0)	1852.64 (394.29; 1149.6, 2901.4)	.930 (.859, .966)	96.12 (–152.42, 224.38)	.354
	Inversed volumetry	2635.97 (552.95; 1655, 4150)	2614.8 (565.49; 1521, 4161)	.994 (.987, .997)	43.32 (–6373, 106.07)	.054
	Optoelectronic volumetry	4694.6 (551.47; 3832, 6128)	4537.03 (534.1; 3743, 6151)	.934 (.377, .982)	139.44 (–115.74, 430.88)	<.001**
	Calculated arm volume based on circumferences	2531.95 (564.85; 1547.3, 4069.8)	2473.23 (545.88; 1516.7, 3910.9)	.986 (.931,.995)	65.71 (–70.07, 187.51)	<.001**
Excessive volume	Traditional volumetry with overflow	481.65 (384.63; –56.9, 1498.2)	498.34 (354.15; –77.9, 1293.3)	.861 (.729, .931)	137.72 (–253.24, 286.62)	.646
	Volumetry without overflow	419.07 (330.83; –128.6, 1285.7)	375.53 (274; 1149.6, 2901.4)	.791 (.606, .895)	138.25 (–227.44, 314.52)	.520
	Inversed volumetry	524.43 (355.2; –140, 1159)	581.17 (378.95; –20, 1494)	.909 (.810, .957)	110.73 (–160.30, 273.78)	.046*
	Optoelectronic volumetry	550.87 (415.75; –201, 1420)	525.03 (399.14; –229, 1358)	.949 (.897, .975)	92.01 (–151.51, 206.19)	.285
	Calculated arm volume based on circumferences	476.93 (367.31; –126.8, 1345.3)	469.24 (367.31; –88.7, 1373.2)	.984 (.967, .992)	45.3 (–81.11, 96.49)	.523

ICC: intraclass correlation coefficient, CI: confidence interval, SEM: standard error of measurement.
*P-value < .05; **P-value < .01.

Table 3. Setup time, mean execution time and mean total time of five different measurement methods (n = 30).

Measurement method	Mean setup time (SD), seconds	*P*-value (ANOVA)	Mean execution time (SD), seconds	*P*-value (ANOVA)	Mean total time (SD), seconds	*P*-value (ANOVA)
Traditional volumetry with overflow	444.00 (11.51)[b]	<.01	275.80 (89.56)[d]	<.01	640.53 (89.11)[g]	<.01
Volumetry without overflow	280.00 (16.80)[c]		55.67 (11.57)[e]		335.67 (11.57)[g]	
Inverse volumetry	362.00 (69.35)		333.70 (209.56)[d]		775.00 (212.57)[g]	
Optoelectronic volumetry[a]			102.67 (26.02)[f]		102.67 (26.02)[g]	
Calculated arm volume based on circumferences			264.13 (26.53)[d]		264.13 (26.53)[g]	

ANOVA: analysis of variance.
[a]Time to open the program (PeroPlus) is included in the execution time.
[b]Statistically significant difference with volumetry without overflow ($P < .01$).
[c]Statistically significant difference with traditional volumetry with overflow ($P < .01$).
[d]Statistically significant differences with optoelectronic volumetry and volumetry without overflow ($P < .01$).
[e]Statistically significant differences with inverse volumetry, optoelectronic volumetry and calculated arm volume based on circumferences ($P < .01$).
[f]Statistically significant differences with traditional volumetry with overflow, volumetry without overflow, inverse volumetry and calculated arm volume based on circumferences ($P < .01$).
[g]Every pairwise comparison of methods showed statistically significant differences between their means ($P < .05$).

ranged between .791 and .984. The calculated arm volume based on circumferences showed the highest ICC of .984. In addition, this method presented the lowest SEM, resulting in a test variation of 45.3 mL between two test occasions by different assessors.

An overview of the results regarding mean setup time, mean execution time and mean total time (±SDs) of the different measurement methods is given in Table 3. In addition, a visual comparison of the results, assisted with the ANOVA post hoc outcomes, is illustrated in Supplemental Figure 1. Regarding the ANOVA post hoc analyses, Games–Howell post hoc analyses were performed since equal variances were not assumed.

Setup time

Volumetry without overflow proved to require the least time, with a mean setup duration of 4 minutes and 40 (±12) seconds. Mean setup time differed statistically significantly between traditional volumetry with overflow and volumetry without overflow ($P < .01$).

Execution time

Mean bilateral execution time was the lowest for volumetry without overflow (56 (±12) seconds). Mean execution time was the highest for inverse volumetry (5 minutes and 34 (±210) seconds) ($P < .01$).

Total time

With regard to the time needed for both setup (if required) as well as a bilateral execution of the measurement, optoelectronic volumetry turned out to be the fastest method, representing a mean time of 1 minute and 43 (±26) seconds. Every pairwise comparison of methods showed statistically significant differences between their means ($P < .05$).

Nine limitations regarding clinical feasibility that were listed in Supplemental Table 1 were supplemented with the following three limitations, retrieved from clinical experience: (1) the device is difficult to apply in patients with limited postural balance; (2) segmental measurements for evaluation of local changes are not provided and (3) indirect measurement of volume (calculations need to

Table 4. Summary table with ranking of the five measurement methods regarding reliability (ICC), time efficiency and clinical feasibility.

		Traditional volumetry with overflow	Volumetry without overflow	Inverse volumetry	Optoelectronic volumetry	Calculated volume based on circumferences
Reliability	*ICC*[a]					
	Outcome (intra/inter)	Intra: .813 Inter: .861	Intra: .777 Inter: .791	Intra: .922 Inter: .909	Intra: .921 Inter: .949	Intra: .987 Inter: .984
	Ranking	4	5	3	2	1
Time efficiency	Outcome (total time), seconds	640.53	335.67	775	102.67	264.13
	Ranking	4	3	5	1	2
Clinical feasibility	*Limitations*					
	Outcome (total score)	6	7	7	5	3
	Ranking clinical feasibility	3	4	4	2	1
Total score		11	12	12	5	4
Total ranking		3	4	4	2	1

ICC: intraclass correlation coefficient.
[a]The presented inter- and intra-rater ICC values are based on excessive volume results.

be performed after the measurement). Finally, these 12 limitations were scored in Supplemental Table 4. Least limitations were seen in the calculated volume based on the circumference method.

A summarizing ranking table is presented in Table 4. Results revealed that the calculated volume based on circumference measurements received the highest overall rank. Therefore, this method is considered as the most appropriate to be used in clinical practice based on our scored items (see Table 4).

Discussion

In terms of reliability, low error rate, low cost, few limitations and time efficiency, volume calculation based on arm circumferences is the best measurement method for evaluating excessive arm volume in patients with BCRL over time in clinical practice.

All five investigated methods showed good to very good *reliability*, which are comparable to previous results.[11,22–26] Nevertheless, it should be noted that previous results are mainly based on measurements executed on the oedematous limb or on a healthy limb. However, we preferred to perform measurements on both arms in order to determine and analyse the excessive arm volume, since it has the advantage of being able to correct for changes in muscle size and subcutaneous fat when monitoring long-term treatment effects. Limited reliability studies did also investigate the measurement error, and of those who did, only a few have reported the formula that was used.[11,27]

Since the volumetry without overflow method has only recently been introduced,[9] no previous publications regarding the clinimetric parameters of this method are available yet. When observing the results of this method obtained in this study, one can notice a slight distinction compared with the other four methods due to relatively lower intra-rater (.777) and inter-rater (.791) ICCs of the excessive arm volumes, corresponding to the SEM values of 146.36 and 138.25 mL, respectively. Nevertheless, these values still represent strong intra- and inter-rater reliability. A potential pitfall that can be causal for this variability might be found in the accuracy of repeatedly indicating the same reference points before the measurement starts. The most important reference point is located in the elbow fold and is defined as the skin

fold which is most centrally located in the elbow fold. Starting from this line, a proximal distance of 10 cm is measured to indicate the reference point required for measuring the total arm volume. In our opinion, a difference in interpretation and perception between different assessors (and even within the same assessor) to define this most centrally located elbow fold can contribute to this variability. As it was shown that volumes calculated from circumferences relative to anatomic (bony) landmarks are more accurate than those from segments using defined distances,[11] an alternative approach in indicating reference points might be helpful to decrease this within-subject as well as between-subject variability.

This is the first study investigating *time efficiency* of the different measurement procedures using a standardized protocol. Consequently, there is little information in the literature available that allows us to compare our findings (Supplemental Table 1). In this study, optoelectronic volumetry showed the least total time required to complete a bilateral measurement (1 minute 42 seconds on average). Previous studies also mentioned optoelectronic volumetry being a quick device, taking only a few seconds,[10,22] to 2 minutes per measurement.[28] One study mentioned that the time required to complete volume measurements using a traditional volumetry device with overflow was 20 minutes,[23] in contrast to the mean total time of 10 minutes 40 seconds in this study. Furthermore, studies reported an average duration of 10 minutes for performing separate girth measurements after which the arm volume was calculated using the formula for a truncated cone.[23,28] In this study, the measurement lasted about 4 minutes and 24 seconds on average using a perimeter. In the study of Damstra et al.,[4] volume measurements of both arms by making use of inverse volumetry required 5 minutes, which is remarkably lower than the time required in this study (12 minutes 55 seconds on average). However, information on whether this time also included calibration time was not provided. In this study, the execution time of the inverse volumetry without the calibration time was 5 minutes 33 seconds on average, which would be comparable with the results of Damstra et al.[4] Another study reported a mean total time of 15 minutes, with the most time spent on the preparation.[29]

Concerning *clinical feasibility*, there is no consistency found in the literature. Moreover, a recent systematic review providing best evidence regarding which measurement method is the most appropriate in measuring lymphoedema concluded that information on feasibility is scarce.[12] Results of our ranking revealed that water displacement methods yield more practical limitations than the calculated volume based on circumference measurements and optoelectronic volumetry.

Some study limitations should be mentioned. Although good to very good reliability was demonstrated in all five methods, the relatively small number of participants might have lowered the variability between participants. However, as stated by Shrout and Fleiss,[19] researchers should try to obtain at least 30 heterogeneous subjects for reliability studies which was established in this study.

Next, an optoelectronic volumetry device primarily designed for lower limbs was used. However, to encounter this hindrance, a strict and standardized protocol regarding sitting posture and measurement procedure was carried out in order to provide unambiguous measurements of the upper limb.

Besides the mentioned limitations, this investigation contains several strengths. First, since we analysed the reliability of the different methods by measuring both the oedematous and the non-oedematous arm, our results can be extrapolated to a patient population as well as to a healthy population or to a patient population without clinical representation of lymphoedema. Second, in order to investigate reliability and time efficiency as accurate as possible, several training moments between assessors were organized ensuring standardization of the measurement procedure.

Third, to eliminate any risk for recall bias between the measurements, the assessor was supported by an independent assistant writing down the values and consequently ensuring blinding of the data.

Calculated arm volume based on circumference measurements proved to be the most reliable and

feasible method to apply in clinical practice, in order to measure the excessive arm volume over time. Hereby, when measurements are performed by the same assessor, a test variation of more than 42 mL should be considered as a change in excessive arm volume, exceeding the (potential) measurement error. In case the measurements are performed by different assessors, a test variation of more than 45 mL exceeds the area of potential measurement errors. The device consists of materials with low costs, and therefore it is easy to self-design a perimeter. Alternatively, it can be purchased as it is commercially available as well. For clinical centres having sufficient financial capacity, an optoelectronic volumeter can also be considered. However, a disadvantage of both methods is the fact that hand volume is not taken into account. Therefore, hand volume should be measured separately, for example, by making use of a hand volumeter[30] or the figure-of-eight method.[31,32] In order to improve the hygienic conditions of the water volumetry method, an antiseptic (e.g. Chlorhexidine) or stabilized chlorine can be added to the water to disinfect the skin.

Since evidence is scarce regarding the recently introduced volumetry without overflow method, future research should focus on this technique. Results revealed that this is a very time-efficient water displacement method showing very strong intra- and inter-rater reliability for measuring the volume of an oedematous and a non-oedematous limb, and strong intra- and inter-rater reliability for measuring the excessive arm volume. We believe that, with the adjustment of the reference point's location, this method can be optimized which will result in smaller SEMs. Next, in this study, we chose a calculated volume based on the circumference measurement method that made use of a perimeter instead of separate girth measurements (using a tapeline), since it comprises several advantages compared to separate girth measurements: (1) the device measures 11 circumferences at once using only one reference point, resulting in quick measurements; (2) only one reference point needs to be marked and measured over time, which might result in smaller measurement errors; (3) since the tapelines are provided with weights (20 g) at their end, the tension of the tapeline on the skin is standardized.[26] However, future studies should compare reliability and correlate these two measures, to investigate whether they could be used interchangeably. Furthermore, analysis of the data revealed that there is a remarkable difference in arm volume measured by the different methods at the oedematous limb, with optoelectronic volumetry representing the largest deviation. Consequently, further research regarding the criterion validity of these methods is warranted to ascertain whether the measured arm volume fully corresponds to the actual arm volume.

Clinical messages

- Calculated arm volume based on circumference measurements proved to be the most reliable, most feasible and very time-efficient method to apply in clinical practice in patients with breast cancer–related lymphoedema, in order to measure the excessive arm volume over time.
- Since the calculated arm volume based on the circumference method does not include an evaluation of hand volume, therapists should measure this separately, for instance, by making use of a hand volumeter[30] or the figure-of-eight method.[31,32]

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Supplemental material

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