Quantitative comparison between the laser scanner three-dimensional method and the circumferential method for evaluation of arm volume in patients with lymphedema

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ABSTRACT

Objective: Several methods are used to evaluate arm volumes. The most commonly used methods are water displacement and the circumferential method (CM), but these techniques have some limitation in application in clinical settings and accuracy. Recently, the laser scanner three-dimensional (LS3D) method was successfully proposed as a valid method for volume measurements of the upper limb in healthy individuals. The aim of the study was to compare, in terms of intraobserver and interobserver reliability, the CM and LS3D method to measure the upper limb in a group of women with upper limb lymphedema.

Methods: There were 200 women with upper limb lymphedema (mean age, 64 ± 9 years; body mass index, 24.72 ± 2.94 kg/m^2) involved in this study. Arm measurements were obtained with both the CM and LS3D method. Statistical analysis was conducted to compare the CM and LS3D method.

Results: Both the CM and LS3D method have a satisfactory level of agreement, but we found some statistically significant differences in terms of some measurements (both circumferential and volume measurements).

Conclusions: The data obtained in this study indicate that the LS3D method could represent a reliable, valid method to measure arm circumferences and volumes in arms with lymphedema, suitable for daily clinical use. It combines precision, reproducibility, and ease of use with the possibility of measuring geometric parameters and shape information of scanned limbs. (J Vasc Surg: Venous and Lym Dis 2018;6:96-103.)

Lymphedema is a condition of localized fluid retention and tissue swelling caused by a compromised lymphatic system, which normally returns interstitial fluid to the thoracic duct, then the bloodstream. The condition can be inherited or can be caused by a birth defect, although it is frequently caused by cancer treatments and by parasitic infections. In particular, arm lymphedema is a potential side effect of breast cancer surgery and radiation therapy that can appear in some people during the months or even years after treatment ends. It is characterized by swelling in the upper quadrant on the ipsilateral side of the operation or irradiation. The reported incidence of this type of lymphedema varies according to the degree of swelling that is used to define clinically significant lymphedema, as does the method of measurement to quantify arm volume.[1] However, a systematic review of 72 studies concluded that it affects approximately one in every five women treated for breast cancer.[2]

Arm lymphedema needs to be measured quantitatively to aid in the assessment of severity at the time of diagnosis and remeasured to assess response to treatments that may be administered. Furthermore, accurate measurement of arm volume is needed in observational studies of arm lymphedema as a complication of local treatment for breast cancer and in research trials of prevention or treatment. Evaluation of the effectiveness of treatments for lymphedema requires an accurate, easy-to-use method for the calculation of arm volume. Nowadays, there are several methods to evaluate arm volumes. The most commonly used methods are water displacement (WD) and the circumferential method (CM). CM represents the most common method in clinical application[3-5]; it is widely used because of its limited cost, but the estimation of arm volume is subject to several potential errors. The formula used for the volume calculation based on circumferential measures presumes that the arm is approximated to a truncated cone, neglecting the swelling typical of the edematous arm. The lack of accuracy is added to the inability to measure the arm's protuberant shape and swelling. WD represents the "gold standard"[6-8] and is a reliable method of measuring limb volume.

Several studies compared these two techniques in terms of accuracy and reliability,[5,7-13] demonstrating that volumes are most accurately measured by

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WD.[12,14,15] However, although it is considered the gold standard,[6-8] many researchers choose not to use the WD method because it is time-consuming, is not portable, presents water spillage and space need,[10,16] and can be unhygienic.[15,17] Considering the difficulties related to the WD method, especially for routine clinical use, the search for alternative methods of volume deter-mination remains a worthwhile pursuit. A precise mea-surement of lymphedema volume is in fact mandatory to determine the effect of therapies and treatments as well as to quantify the pathologic impairment.

The laser scanner three-dimensional (LS3D) method was successfully proposed recently as a valid method for volume measurements. The LS3D method is generally applied in orthopedics, in design of orthoses and other health and well-being applications. It has the advantages of being relatively inexpensive, fast, accurate, and noninvasive, and it has no contact with the patient.[18] The LS3D method has been studied in terms of accuracy and reproducibility and compared with the gold standard. McKinnon et al[19] compared WD and digital laser scanning in a series of inanimate objects of known and unknown volume. A similar comparison was made in measuring the volume of upper limbs of 10 healthy volunteers. McKinnon demonstrated that laser scanning has similar accuracy and superior reproducibility compared with the WD method. In our previous work, we compared, in terms of intraobserver and interobserver reliability, the CM and LS3D method for upper limb measurement in a group of healthy subjects.[20] We concluded that the LS3D method could be an innovative and valid method of measuring the upper limb volume that could be used instead of CM.

From these considerations, the aim of this study was a comparison between the circumferential measurements—in general performed in clinical routine—and those obtained with an LS3D system in a large group of subjects with upper limb lymphedema related to breast cancer treatments.

ARTICLE HIGHLIGHTS

- **Type of Research:** Prospective cohort study
- **Take Home Message:** Bilateral arm volumes of 200 women with unilateral lymphedema were assessed to compare segmental circumference measurements with three-dimensional laser measurements. There seemed to be good correlation between the two methods, with a good level of agreement for both arms of the patients.
- **Recommendation:** The authors found the three-dimensional laser volume measurement technique a good alternative to segmental circumference tape measurements to assess the volume of the limb with lymphedema and to compare it with the volume of the normal arm.

METHODS

There were 200 women with upper limb lymphedema (mean age, 64 ± 9 years; mean weight, 64.27 ± 9.58 kg; mean height, 161.05 ± 5.89 cm; and mean body mass index, 24.72 ± 2.94 kg/m^2) involved in this study. Patients with unilateral lymphedema of the upper limb (after quadrantectomy or mastectomy with axillary dissection for breast cancer) were enrolled. On the contrary, the exclusion criterion was the presence of bilateral lymphedema. The inclusion criterion of unilateral lymphedema was introduced to make possible the comparison of the lymphedema's severity with the patient's healthy condition, which is assumed to be the contralateral limb.

Participants were recruited from the Palliative Care, Pain Therapy, and Rehabilitation Department, IRCCS Fondazione Istituto Nazionale dei Tumori, Milano, Italy. They were all adult women who gave written informed consent.

Similar to the study conducted by Cau et al, both arms of each participant were measured by the CM and LS3D method. The measurements were performed by expert operators who had previous experience with arm measurements in patients with lymphedema and who also received special training for the study, especially in measurement by the LS3D method. The study was approved by the Ethics Committee of the institute; written informed consent of the patients was obtained.

CM measurements. The upper limb circumferences were measured with a normal tape measure (1-mm sensibility). The participants were in standing position, with arms stretched at the shoulder level with the palm of the hand down. Measurements were made corresponding to marks made on the skin using a dermatologic pen from the ulnar styloid process of the wrist to 20 cm proximal to the lateral epicondyle (corresponding to the inferior extremity of the deltoid muscle) with 4-cm intervals. To uniquely define the arm and the upper arm, one additional point was detected corresponding to the olecranon, indicated as the mid-dle point. To not influence the operator, all marked points were deleted from the skin surface after each measurement.

The numbers of measured points depend on the length of arm. A variable number between 9 and 10 points was considered. A general representation of the measured points is shown in Fig 1.

The arm volume was calculated by the frustum formula[21]:

$$\text{Volume} = \sum \frac{\left(x_{(i+1)}{}^2 + x_i{}^2 + x_i . x_{(i+1)}\right)}{3\pi}$$

where $x_{(i+1)}$ and x_i are the circumferences corresponding

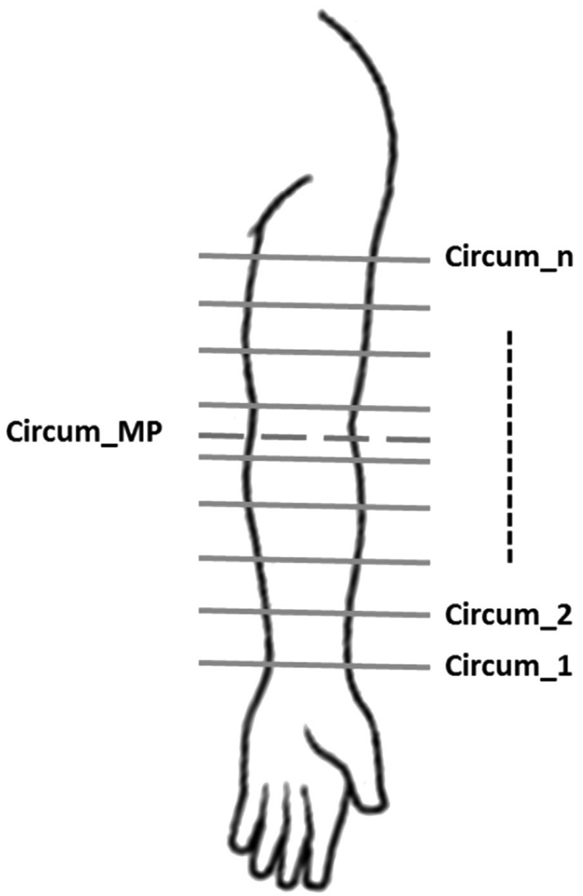

Fig 1. A representation of the measurement points in the circumferential method (CM). The *dotted line* is the middle point (*MP*).

to two consecutive sections. The final volume is determined by adding the volume of the subsections together. The forearm volume is defined by summing all the subvolumes from the wrist to the middle point; the upper limb volume is defined by summing all the subvolumes from the middle point to the most prox-imal point.

LS3D method measurements. A hand-held LS3D system (O&P Scan Rodin4D, Pessac, France; laser peak power, 1 MW; wavelength, 670 nm; class I laser product) was used. Resolution of this scanner model is 0.1 mm, and the absolute accuracy is 0.75 mm. The LS3D system consists of a receiver with a laser scanner (wand probe), a transmitter, and a signal processing unit. Data are saved and processed using a commercial laptop. To guarantee proper accuracy during the scanning phase, it is necessary to ensure that subjects maintain a stable position for the entire duration of measurement (in general, 2-3 minutes). To achieve this stability in this study, the participants were standing with arms stretched and the hands resting on a stand at the same level as the shoulders. The transmitter is used as a relative coordinate system; it produces a magnetic wave so that the receiver can calculate its position and orientation in space. To ensure correct scanning, the transmitter was placed in proximity to the subject at the maximum distance of 1 m in a fixed position on the stand where the hand was held. Measurements were taken at the same marker points previously described for the CM. Overlapping sweeps of the whole arm were made with the scanner (typically, five to seven sweeps for each acquisition), with care to include the region previously considered for CM measurements. To reproduce the exact position of the markers on the digital surface, a laser pointer was used. A series of tags were thus created on the point cloud (defined as the set of points that represent the external surface of the scanned object). As the data were collected, a three-dimensional image was displayed immediately on the computer screen, and the data file was stored. Data were processed by dedicated software, Rodin4D (version 5.6). The processing phase was divided into two main steps:

1. Three-dimensional surface definition: a triangular mesh was generated and a closed isosurface was created.
2. Geometric parameters definition: by means of the laser scanner tags, all circumferences previously identified for CM were detected on the three-dimensional surface. These circumferences were used to identify the corresponding subvolumes as previously defined for the CM.

Parameters. To develop the clinical scanning protocol, two types of parameters were defined: circumferential measures (C) and volume measures (V).[20] Similar to CM, the same series of linear measures were taken on the arm's length with an interval of 4 cm (from C_1 to C_10). C_MP is a middle point defined as a measure corresponding to the olecranon. All subvolumes in correspondence with the circumferential points were defined. The total volume (V_TOT) was calculated from C_1 point to the more proximal point on the arm. Two additional volumes were indicated, V_FA and V_UA, defined, respectively, as the forearm volume and the upper arm volume (Fig 2).

Statistical analysis. Statistical analysis was conducted using SPSS (version 19.0; IBM Corp, Armonk, NY). The Kolmogorov-Smirnov test was necessary to verify whether the parameters were normally distributed. Descriptive statistics summarized circumference and volume values. Mean and standard deviation or, alter-natively, median and interquartile range were calculated, depending on data distribution. Correlation between the CM and the LS3D method was analyzed, and the Spearman correlation coefficient was calculated. To evaluate the level of agreement between the two methods, a Bland-Altman plot was performed. Statistical differences between CM and LS3D method were

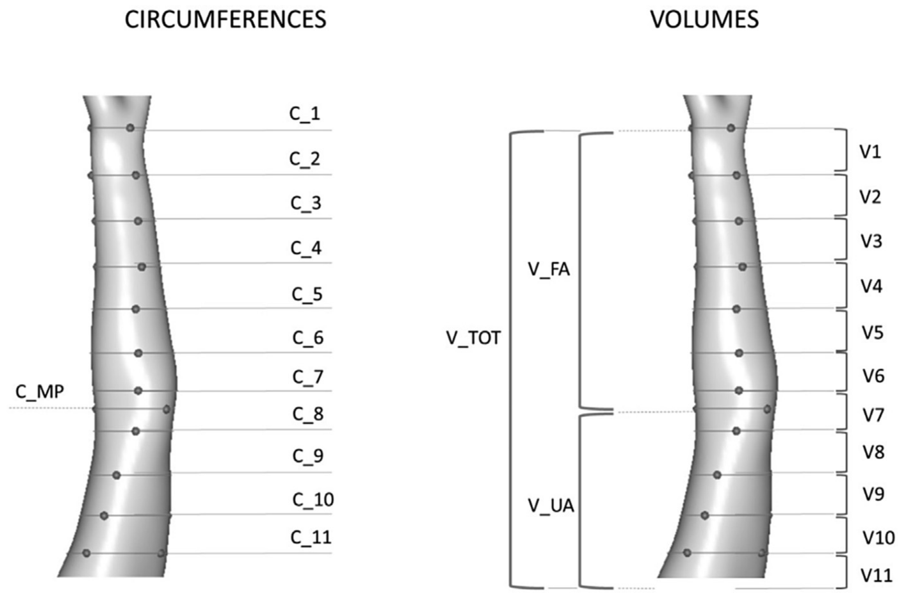

Fig 2. The three-dimensional scanning protocol parameters: *C_MP*, middle point at the olecranon level; *V_TOT*, total volume; *V_FA*, forearm volume; *V_UA*, upper arm volume.

highlighted using a nonparametric test, and a Wilcoxon test was performed. Null hypotheses were rejected when probabilities were below .05 ($P < .05$).

RESULTS

Comparison between CM and LS3D method. Fig 3, *A* represents the trend of the pathologic arm volume data measures (CM vs LS3D method). The Spearman coefficient of correlation between volumes determined from CM and LS3D volumes was good ($R^2 = 0.738$; $P < .05$); it indicates a good proportionality between the two methods. In Fig 3, *B*, the Bland-Altman plot is displayed. It is a scatterplot of the mean of the CM and LS3D method plotted against the difference between the two methods. It provides a visual representation of the level of agreement and in particular of the difference in volume (V_TOT CM − V_TOT LS3D) determined by both methods. The horizontal lines represent the mean of the differences and the mean difference ± 1.96 * standard deviation. The average of the differences allows us to estimate whether one of the two methods underestimates or overestimates the volume measure compared with the other. The other two lines represent the confidence interval. If the points on the graph are between the two lines, the two methods provide consistent results.

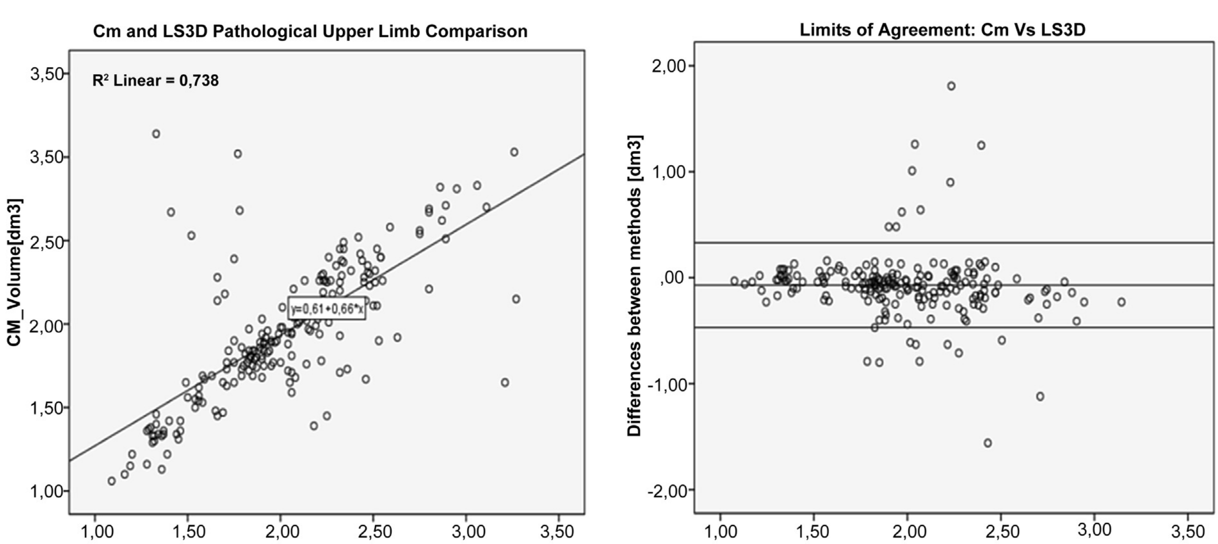

Fig 3. Level of agreement between circumferential method (*CM*) and laser scanner three-dimensional (*LS3D*) method for the pathologic arm.

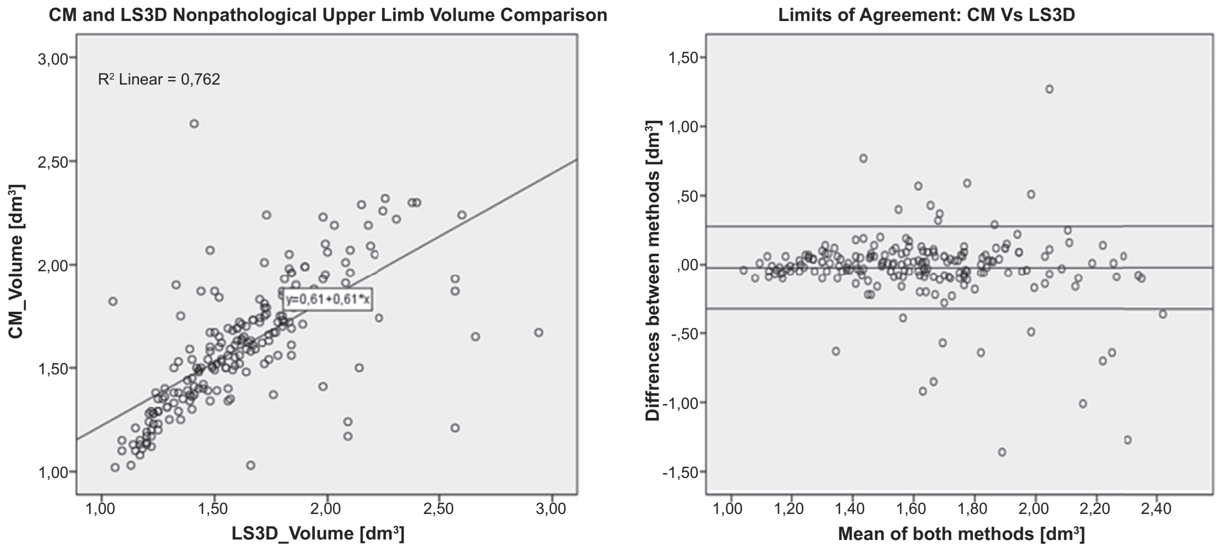

Fig 4. Level of agreement between circumferential method (*CM*) and laser scanner three-dimensional (*LS3D*) method for the nonpathologic arm.

Table I. Circumferential (*C*) and volumetric (*V*) parameters for circumferential method (*CM*) and laser scanner three-dimensional (*LS3D*) method evaluations for the pathologic arm

	Unit	CM, mean or median (SD or QR)	LS3D, mean or median (SD or QR)
C_1	mm	170 (20)	181 (23)[a]
C_2	mm	185 (38.8)	192 (40.7)[a]
C_3	mm	211 (40)	218.5 (41.8)[a]
C_4	mm	240 (40)	250 (44.7)[a]
C_5	mm	260 (40.5)	270.5 (41.7)[a]
C_6	mm	270 (40)	284 (38.8)[a]
C_7	mm	270 (39.5)	282 (33.8)[a]
C_8	mm	280 (40)	292 (40.7)[a]
C_9	mm	290 (40)	302.5 (47)[a]
C_10	mm	300 (50)	313 (55)
C_11	mm	300 (45)	315 (52.5)
C_MP	mm	N/A	282 (29.0)
V_1	dm^3	0.1 (0.03)	0.09 (0.03)
V_2	dm^3	0.12 (0.05)	0.13 (0.03)[a]
V_3	dm^3	0.16 (0.07)	0.17 (0.07)[a]
V_4	dm^3	0.2 (0.07)	0.21 (0.08)[a]
V_5	dm^3	0.18 (0.05)	0.24 (0.08)[a]
V_6	dm^3	0.23 (0.05)	0.24 (0.06)[a]
V_7	dm^3	0.24 (0.06)	0.24 (0.07)
V_8	dm^3	0.25 (0.08)	0.27 (0.09)[a]
V_9	dm^3	0.27 (0.09)	0.28 (0.09)[a]
V_10	dm^3	0.28 (0.08)	0.265 (0.09)
V_ FA	dm^3	N/A	1.15 (0.31)
V_ UA	dm^3	N/A	0.91 (0.25)
V_ TOT	dm^3	1.91 (0.56)	2.005 (0.59)[a]

MP, Middle point; *N/A*, not available; *QR*, quartile range; *SD*, standard deviation; *V_FA*, forearm volume; *V_TOT*, total volume; *V_UA*, upper arm volume. When the data distribution was normal, mean (SD) was reported; when the data distribution was not normal, median (QR) was reported.

[a] $P < .05$, CM vs LS3D.

Table II. Circumferential (*C*) and volumetric (*V*) parameters for circumferential method (*CM*) and laser scanner three-dimensional (*LS3D*) method evaluations for the nonpathologic arm

	Unit	CM, mean or median (SD or QR)	LS3D, mean or median (SD or QR)
C_1	mm	160 (19)	170 (16)[a]
C_2	mm	165 (25.5)	170.5 (23)[a]
C_3	mm	181.5 (30)	190 (30.7)[a]
C_4	mm	210 (35)	215.5 (34.8)[a]
C_5	mm	230 (35.5)	237 (35)[a]
C_6	mm	240 (30)	249 (32)[a]
C_7	mm	245.5 (30.5)	253 (33.2)[a]
C_8	mm	250 (40)	263.5 (41.5)[a]
C_9	mm	267.5 (45)	279 (48.5)[a]
C_10	mm	280 (50.5)	294 (53)[a]
C_11	mm	290 (55)	299 (57.3)[a]
C_MP	mm	N/A	253 (22.4)
V_1	dm^3	0.085 (0.01)	0.07 (0.02)[a]
V_2	dm^3	0.1 (0.04)	0.09 (0.03)[a]
V_3	dm^3	0.12 (0.04)	0.13 (0.04)
V_4	dm^3	0.15 (0.05)	0.16 (0.05)[a]
V_5	dm^3	0.22 (0.06)	0.18 (0.05)[a]
V_6	dm^3	0.19 (0.05)	0.19 (0.05)
V_7	dm^3	0.2 (0.06)	0.2 (0.05)
V_8	dm^3	0.22 (0.07)	0.22 (0.08)[a]
V_9	dm^3	0.24 (0.08)	0.24 (0.08)
V_10	dm^3	0.25 (0.09)	0.24 (0.11)
V_ FA	dm^3	N/A	0.84 (0.15)
V_ UA	dm^3	N/A	0.75 (0.19)
V_ TOT	dm^3	1.59 (0.043)	1.59 (0.44)

MP, Middle point; *N/A*, not available; *QR*, quartile range; *SD*, standard deviation; *V_FA*, forearm volume; *V_TOT*, total volume; *V_UA*, upper arm volume. When the data distribution was normal, mean (SD) was reported; when the data distribution was not normal, median (QR) was reported.

[a]$P < .05$, CM vs LS3D.

The same analysis was performed for the nonpathologic arm. Results are shown in Fig 4. For the contralateral side, the Spearman coefficient was also good ($R^2 = 0.762$; $P < .05$), and a good proportionality between the two methods was proved.

Statistical analysis results for method comparison between the CM and the LS3D method are summarized in Tables I and II, respectively, for the pathologic and contralateral arms. For the arm affected by lymphedema, all the circumferential measurement parameters were statistically different. Statistical differences of volume measurements were found except for two parameters, V_07 and V_10. Total volume is statistically different in the LS3D method compared with CM. Mean total volumes were 1.91 ± 0.56 dm^3 and 2.00 ± 0.59 dm^3 in the CM and LS3D method, with a difference between the two methods of −0.09 dm^3.

In Table II, the results for the nonpathologic arm are reported. In this case, all circumferences were statistically different in both methods. Volume comparison, instead, showed no differences in subvolumes V_3, V_6, V_7, V_9, and V_10 and no statistical differences for the entire arm volume V_TOT.

DISCUSSION

Upper limb lymphedema remains a feared consequence of the treatments for breast cancer. Early detection of lymphedema is required for early intervention and optimal treatment outcomes,[4,22] and the use of an accurate and reliable method of volume measurement is mandatory. The literature reports several papers in which methods for the measurement of upper limb volumes are described and compared (in particular the CM and WD methods[5,7-15,23-27]). The WD method is considered the gold standard.[6-8] However, it is too cumbersome and messy to be used in routine clinical practice. In addition, one of the main limits of this method is the inability to highlight and to measure swelling and shape of the arm, information that is important for clinicians in treating patients with lymphedema. Lymphedema, in fact, is not necessarily uniform in distribution and may instead develop in a localized arm segment, often around the elbow, in the distal forearm, or in the proximal upper arm. Localized swelling, possibly from weaker lymphatic vessels failing first, may precede generalized arm lymphedema.[28] In the clinical setting, the most routinely used method is the CM. However, it has been demonstrated that the estimation of the arm measure with this method is subject to errors mainly related to the use of an approx-imated formula for the volume calculation (frustum formula). These errors could be more important in case of lymphedema when the protuberant shape is more evident.

Cau et al[20] have recently proposed the use of a new technology based on the LS3D method to measure the arm volumes in healthy subjects, finding promising results. The obtained results showed a good correlation between the CM and LS3D method, and a good level of agreement was highlighted by the Bland-Altman plot for the pathologic limb more than for the contralateral limb.

Concerning the volume measurements in pathologic and nonpathologic arms, in the comparison between the CM and LS3D method, the number of subvolumes statistically different between the two methods was different (8/10 for the pathologic arm and 5/10 for the contralateral arm). The reason could be related to the shape of the arm; whereas in the arm with lymphe-dema, the swelling and protuberant shape are promi-nent, the contralateral side is most conditioned by the presence of fat layers, in general most uniformly distrib-uted in each section of the arm. In this latter case, the frustum formula seems to better approximate the vol-ume of the arm (the geometry of the arm is closer to a cone shape). This explanation is even more supported by the literature; in a comparative study between the LS3D method and CM in healthy subjects, Cau et al re-ported a high number of differences between the two methods (7/10 subvolumes were statistically different in the comparison between methods). In fact, in lean subjects, the arm shape is anatomically defined (mus-cles are more evident, there are fewer fat layers, and the landmarks are more visible). Also in this case, the LS3D method seems to be more suitable for the volume and shape detection with respect to the CM, in which the geometric approximation of the volume returns a wrong measure.

CONCLUSIONS

These results indicate that the LS3D method could represent a reliable, valid method to measure arm circumferences and volumes in arms with lymphedema, suitable for routine clinical use. It combines precision, reproducibility, and ease of use with the possibility of measuring geometric parameters and shape information of scanned limbs; these positive aspects justify the costs of use of the LS3D method in a clinical setting. The cost includes mainly the purchase of the scanner and the training of personnel. In terms of time acquisition, as it takes approximatively 5 minutes for the arm, this process is not so time-consuming. For this reason, the cost-benefit ratio is positive for the laser scanner procedure.

Future research could address the validity of data obtained in quantifying the effects of treatments commonly used for lymphedema (comparing volume measurements before and after treatment). In this case, it is mandatory to optimize the landmarked identification procedure to make possible the comparison before and after measurement. Another use of this method could be the correlation between arm volumes and upper limb function; in addition, it could be interesting to extend the use of the LS3D method to other conditions, such as lymphedema of the lower limbs.

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AUTHOR CONTRIBUTIONS

Conception and design: NC, MG, VC, AB, AC
Analysis and interpretation: NC, MG
Data collection: AG, IB, GP
Writing the article: NC, IB, GP
Critical revision of the article: MG, VC, AG, AB, AC
Final approval of the article: NC, MG, VC, AG, IB, GP, AB, AC
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NC and MG contributed equally to this article and share first authorship.

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