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Standardized measurements used to order compression garments can be used to calculate arm
volumes in order to evaluate lymphedema treatment

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Abstract

Background: Lymphedema treatment outcome can be evaluated by calculating estimated limb volumes directly by water displacement (plethysmography; PG), or indirectly by circumference measurements and using the formula for a truncated cone. We assessed the correlation between PG and circumference volume measurements to assess whether the correlation is acceptable, and if circumference measurements can be used to accurately assess arm volume.

Methods: Ten women with unilateral lymphedema following breast cancer treatment with a mean age of 66 (range, 50–83) years volunteered for arm volume estimates by PG and circumference measurements. The coefficient of variation (CV%) for all methods was calculated. Two Excel-based formulas of the truncated cone were developed; one for fixed 4-cm intervals leading to 10 volume segments (CM-10-VS) and one for varying intervals leading to 4 volume segments (CM-4-VS).

Results: The CV% was 0.609 for PG, 0.628 for CM-10-VS, and 0.632 for CM-4-VS. As expected, PG generated a significantly larger volume of both arms because it includes the hand. The difference between CM-10-VS and CM-4-VS measurements was not significant. All three measurement methods showed a high correlation coefficient ranging 0.813–0.915, and a regression coefficient ranging 0.863–1.089. The excess volume, which is used to determine treatment outcome, showed the respective values of 0.932 to 0.978 and 0.963 to 1.020, respectively

Conclusion: Using circumference measurements, identical to those used when ordering made-to-measure compression garments, speed up volume measurements and can be used safely to evaluate lymphedema treatment outcome.

INTRODUCTION

The incidence of breast cancer-related lymphedema ranges 1% to 89% depending on the combination of therapy chosen, including mastectomy, sentinel node biopsy, standard axillary lymph node dissection, and/or postoperative irradiation.[1] Since the introduction of sentinel lymph node (SN) biopsy and the avoidance of axillary clearance, the frequency of lymphedema has decreased.[2] However, axillary clearance and irradiation is used when the SN-biopsy is positive.[3] No curative intervention for lymphedema currently exists and treatment is aimed at reducing and controlling swelling to improve functionality and the comfort of the patient. The excess volume in an untreated chronic lymphedema consists of accumulated lymph and adipose tissue.[9-12] Conservative treatment such as Complex Decongestive Therapy (CDT) or Controlled Compression Therapy (CCT) is preferred when accumulated lymph causes arm swelling and pitting is seen.[4-8] 'Pitting' means that a depression forms after using the thumb to put pressure on edematous tissue, resulting in lymph being squeezed into the surroundings. To standardize the pitting-test, one presses as hard as possible with the thumbon the region to be investigated for one minute.[9, 10] The amount of depression is estimated in millimeters. Arm swelling dominated by hypertrophied adipose tissue shows little or no pitting. Chronic inflammation probably causes the adipose tissue to increase in volume.[11-14] Consequently, excess adipose tissue can be completely removed using liposuction, resulting in a complete reduction of the arm swelling with no recurrence if the compression garments are worn continuously.[4-8]

A common method for estimating arm volume is water plethysmography (PG), where the displaced water equals the arm volume including the hand. This set-up is sometimes cumbersome because access to water, a water tank with an outflow, and a scale with high accuracy are required. Nevertheless this method is considered the gold standard.[4, 23, 24]

Another way to estimate arm volume is circumference measurements along the arm, which uses a tape measure to take several measurements of the circumference of the arm a standard distance apart, usually 4 cm. Each volume segment is measured according to the formula of a truncated cone. Depending on the arm length, this leads to 10 volume segments in most cases (circumference measurements-10-volume segments; CM-10-VS). By summing the segments of the arm, the estimation correlates well with water displacement methods.[15-20] Just as with PG, the normal contra-lateral arm is used as the reference when calculating the excess

volume.[21-22] This method does not include the hand volume because the hand is oval in shape, and the formula for the truncated cone cannot be used.

Elastic compression garments are available in standard sizes and as made-to-measure. They are available in varying compression classes, usually I to IV, where I provides the lowest compression. It is important that the garment fits correctly and provides adequate graded compression. Therefore, we use made-to-measure garments. When ordering these garments, the circumference measurements are taken by the physiotherapist at 5 levels starting at the wrist and extending to the most proximal part of the arm. The distance between the circumferential measurements varies depending on the size of the arm (**Figure 1**). This leads to 4 volume segments (circumference measurements-4-volume segments; CM-4-VS), which can be calculated analogous to that described for CM-10-VS.

In our everyday set-up, measurements are first taken to estimate the volumes of both arms and determine the excess volume in the swollen arm; then measurements are taken to order the garments.

We wanted to estimate the correlation between PG and circumference measurements taken either at CM-10-VS or at varying intervals along the arm by CM-4-VS. The latter is used to take measurements for the made-to-measure compression garments. If the correlation is good, then only the latter measurement is necessary and could speed up the volume assessment procedure.

MATERIALS AND METHODS

Patients

Ten women with unilateral lymphedema following breast cancer surgery with a mean age of 66 (range, 50–83) years volunteered to participate in the study. The volume of both arms was estimated by circumference measurements and PG.

Coefficient of variation

To calculate the coefficient of variation (CV%) for each method, 3 physiotherapists had one of their arms measured 10 times by another physiotherapist using each method.

The mean intra-assay CV% could thus be calculated according to the formula:

Fel! Ogiltigt inbäddat objekt.

Volume measurements

To calculate arm volumes, PG and circumference measurements were used. Circumference measurements can be converted into volumes by calculating each volume segment using the formula of the truncated cone and adding these volumes together to comprise the whole arm volume; this method does not include the hand. Both of the patients' arm volumes were measured. All measurements were performed by the same physiotherapist.

Plethysmography (PG)

A 24-liter glass cylinder filled with water at about 37ºC was used. The arm was immersed, until the most proximal part of the arm reached the surface of the water. The displaced water was weighed on a scale to the nearest 1 g (1 gram water equals 1 ml). Then the glass cylinder was filled with water again before the next measurement (**Figure 2**). When measuring arms with PG, the volume of the hand is included in the total volume, whereas it is not when circumference measurements are used.

Circumference measurements

Circumference measurements were taken using a nylon tape measure with an accuracy of 1 mm. The tape measure was placed snugly around the arm without tightening the tape.

(a) CM-10-VS: Circumference measurements taken at 4-cm intervals along the arm from the wrist to the shoulder, usually resulting in 11 circumference measurements being made when the arm is 40 cm long; thus, 10 volume segments are obtained. In 2 patients, 12 circumference

measurements were taken because their arm was 44 cm long from the wrist to the axilla (**Figure 3**).

(b) CM-4-VS: When ordering made-to-measure compression garments, the arm is divided into two segments; wrist to elbow and elbow to the proximal part of the arm, marking the ends with a pen. Each segment is divided into two equal sub-segments, which are also marked. Circumference measurements are taken at each marking along the arm, starting at the wrist, while recording the distance to wrist for each measurement. This gives 5 circumference and 4 distance measurements as well as 4 volume segments.

Computer program

Two Excel-based software programs were developed to calculate volume using circumferential measurements either 4 cm apart or at variable distances as described above, treating each segment as a truncated cone. In the software the volume of each segment is summed to compute the total arm volume. The normal and lymphedematous arms are measured in the same way. The volume of a truncated cone is calculated according to the formula below:

where V is the volume of the segment, C_1 and C_2 are the circumferences at the ends of the segment, and h is the distance between them (segment height).

Statistical analysis

Measurements are presented using the mean, standard deviation (SD), and range. The significance of differences was assessed using the Student's *t*-test for paired observations, and probabilities of 0.05 were accepted as significant. Non-parametric calculations were also performed, finding no difference in statistical significance. Linear regression analysis was performed to obtain the coefficient of regression (β) (i.e., the slope) with a 95% confidence interval (95% CI), and the coefficient of correlation (r). The excess or 'edema volume' is defined as the difference in volume between the lymphedematous (swollen) arm and the normal arm.

Ethics

The study compares two established volume measurement regimens. Under these circumstances, approval from the local *ethics committee* is not needed for standard hospital procedures. All patients provided informed consent. The study was in accordance with the Helsinki Declaration of 1975, as revised in 1983, and was approved by the institutional review board at the Department of Plastic and Reconstructive Surgery, Örebro University Hospital, Örebro, Sweden.

RESULTS

Coefficient of variation

The CV% for volume calculations were 0.628 for CM-10-VS, 0.632 for CM-4-VS, and 0.609 for PG.

Volume measurements

Swollen arm

PG showed a mean volume of 3138 ml. This volume also includes the hand, so it generates a larger volume compared with the volume based on CM-10-VS, which was 2972 ml, and with CM-4-VS, which was 2916 ml (**Table I**). The mean difference between CM-10-VS and CM-4-VS was 56 (range, -179 – 308) ml, indicating that fewer volume segments generate a smaller volume, but the difference was not statistically significant. As could be expected, the difference between PG and CM-10-VS and PG and CM-4-VS was larger because the hand volume was included in the PG measurements; 166 (range, -111 – 646) ml and 222 (-44 – 647) ml, respectively. These differences were statistically significant. Between the PG and CM-10-VS and the PG and CM-4-VS measurements, the *P* values were $P<0.0403$ and $P<0.0129$, respectively. There was a high correlation between all the methods with a correlation coefficient of > 0.880 and a regression coefficient of close to 1.
 (**Table II**).

Normal arm

PG showed a mean volume of 2498 ml for normal arms. Just as when measuring the swollen arm, this volume also includes the hand, resulting in a larger volume than those acquired with circumference measurements. Based on CM-10-VS and CM-4-VS, the mean volumes were 2390 ml and 2363 ml, respectively (**Table I**). The mean difference between CM-10-VS and CM-4-VS was 26 (range, -224 – 210) ml, indicating that fewer volume segments generate a smaller volume, but that the difference was not statistically significant. As seen previously in the swollen arm, the difference between PG and CM-10-VS and PG and CM-4-VS was 108 (range, -107 – 483) ml and 134 (-28 – 545) ml, respectively, and larger in the PG measurement because the hand volume is included in the measurement. A statistical difference was found between the PG and CM-4-VS measurements ($P<0.0463$). There was a high correlation between all the methods, with a correlation coefficient of > 0.813 and a regression coefficient of close to 1 (**Table II**).

Excess volume

The volume difference between the swollen and the normal arm is equal to the excess volume ('lymphedema volume'). PG showed a mean excess volume of 641 ml. Based on CM-10-VS and CM-4-VS, the mean excess volume was 582 ml and 553 ml, respectively (**Table I, Figure 4**). The mean difference between CM-10-VS- and CM-4-VS-generated excess volumes was 29 (range, -46 – 97) ml, but the difference was not statistically significant. The difference between PG and CM-10-VS and PG and CM-4-VS was 59 (range, -82–164) ml and 88 ml (-22–208) ml, respectively. This difference was statistically significant. Between PG and CM-10-VS and PG and CM-4-VS measurements, the *P*-values were $P<0.0455$ and $P<0.0033$, respectively. There was a high correlation between all the methods with a correlation coefficient of > 0.932 and a regression coefficient close to 1 (**Table II, Figures 5, 6, and 7**).

DISCUSSION

Several studies have compared water displacement techniques and volume measurements based on circumference measurements. Since many different measurement protocols have been used, it is difficult to make comparisons. For example, Stranden[17] studied lower leg volume; Karges et al[16] measured the arm with plethysmography with the proximal measurement point somewhere between mid-humerus and axilla; Taylor et al[19] used an upper boundary of 65% of the distance from the elbow (olecranon) to the shoulder tip (acromion); Sander et al[20] used the axilla as the proximal point, whereas, in our study, the arm was submerged into water up to the same level where measurements were taken when ordering compression garments (as proximal as possible).

Regarding circumference measurements, Karges et al[16] made circumference measurements from the finger metacarpophalangeal (MCP) joint to between mid-humurus and axilla; Tayler et al[19] measured from mid ulnar styloid to the 65% mark as described above; and Sander et al[20] used the axilla as the proximal point, whereas we measured as we would for ordering made-to-measure garments.

The water displacement volume is generally larger. One reason for this is that water displacement also measures the volume of the hand. When the hand is substracted from the total volume of the arm, the water displacement volumes have been larger compared with circumference measurements, using the equation of a frustum,[16,20] but in other studies it was the opposite.[17,19] Sander et al[20] reported a good correlation between water displacement and circumference measurments at 3-, 6-, and 9-cm intervals when measuring arms and using the the frustum method. Either the 6- or 9-cm intervals are recommended to clinicians, while the 9-cm interval method is recognized as the most efficient one. This agrees with our findings where the segments are longer, around 10 cm, but still provide good correlation between both circumference measurments at 4 cm and water displacement.

There are a number of errors that can occur during the measurement process, but the standard deviation becomes small with an experienced physiotherapist.[20] As in this study, both arms should be measured simultaneously so that the excess volume in the swollen arm can be calculated with the contra-lateral arm serving as a control, thus avoiding the effect of casual variations in the general body mass index. Natural asymmetry might mask early development of lymphedema. By measuring the arm in its pre-edematous state, i.e. before breast cancer

surgery, this can be avoided.[18, 22]

Karges et al concluded that both water displacement and circumference measurements are highly accurate,[16] which is in accordance with our findings. Clinicians can, therefore, use either method. There are differences and these measures are not interchangeable. Therefore, one should use one method throughout.[16]

The volumes generated with the three different methods and the corresponding excess volumes correlate well. The difference between the two circumference-based measurements was not statistically different and paralleled plethysmography measurements. The correlation was high (0.978) with a coefficient of regression of 1.020. In order to follow treatment outcome during clinical use, the circumference measurements recorded when ordering made-to-measure compression garments can therefore be used to calculate arm and excess volumes, thus speeding up the procedure.

Disclosure Statement
Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Tables

Swollen arm	PG	CM-10-VS	CM-4-VS
Number	10	10	10
Mean	3138	2972	2916
SD	455	367	404
Min	2340	2322	2205
Max	3686	3442	3330

Normal arm	PG	CM-10-VS	CM-4-VS
Number	10	10	10
Mean	2498	2390	2363
SD	333	295	307
Min	1970	1966	1879
Max	3010	2914	2919

Excess volume	PG	CM-10-VS	CM-4-VS
Number	10	10	10
Mean	641	582	553
SD	217	210	201
Min	356	263	258
Max	1010	979	903

Table I. Mean, SD and range of measured volumes (ml). CM-10-VS, circumference measurements-10-volume segments; CM-4-VS, circumference measurements-4-volume segments; PG, plethysmography.

Swollen arm	coefficient of correlation (r)	coefficient of regression (β)	95% CI	(β) *p*-value
PG vs CM-10-VS	0.880	1.089	0.608-1.570	0.0008
PG vs CM-4-VS	0.867	0.976	0.518-1,434	0.0012
CM-10-VS vs CM-4-VS	0.948	0.863	0.628-1.098	0.0001

Normal arm	coefficient of correlation (r)	coefficient of regression (β)	95% CI	(β) *p*-value
PG vs CM-10-VS	0.813	0.915	0.381-1.450	0.0042
PG vs CM-4-VS	0.838	0.907	0.425-1.388	0.0025
CM-10-VS vs CM-4-VS	0.915	0.880	0.564-1.196	0.0002

Excess volume	coefficient of correlation (r)	coefficient of regression (β)	95% CI	(β) *p*-value
PG vs CM-10-VS	0.932	0.963	0.657-1.269	0.0001
PG vs CM-4-VS	0.946	1.020	0.736-2.304	0.0001
CM-10-VS vs CM-4-VS	0.978	1.020	0.843-1.197	0.0001

Table II. Regression analysis of arm volumes and excess volumes as measured by plethysmography (PG) and circumference measurements with 10 (CM-10-VS) and 4 (CM-4-VS) volume segments.
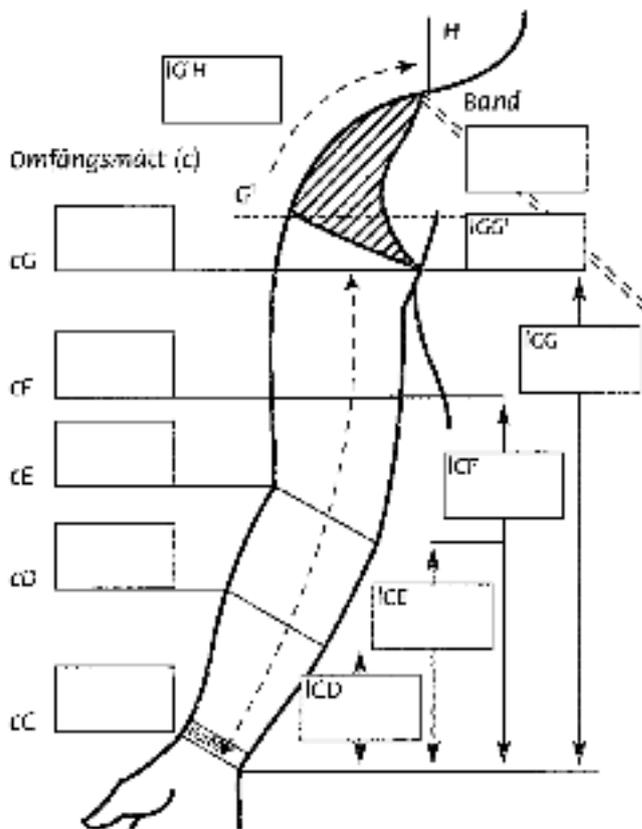
Figures

Figure 1. The four volume segments generated when taking circumferential measurements to order made-to-measure compression garments. In the figure, cC, cD, cE, cF, and cG represent the circumferences. ICD, ICE, ICF, and ICG represent the proximal distance of each volume segment to the wrist. Using the formula for a truncated cone (frustum), the volume of each segment can be calculated. The sum of the volume segments equals the arm volume (hand not included), i.e. CM-4-VS. The same goes for CM-10-VS, where the height of each segment is set at 4 cm.

Figure 2. Measuring the arm volume with plethysmography.

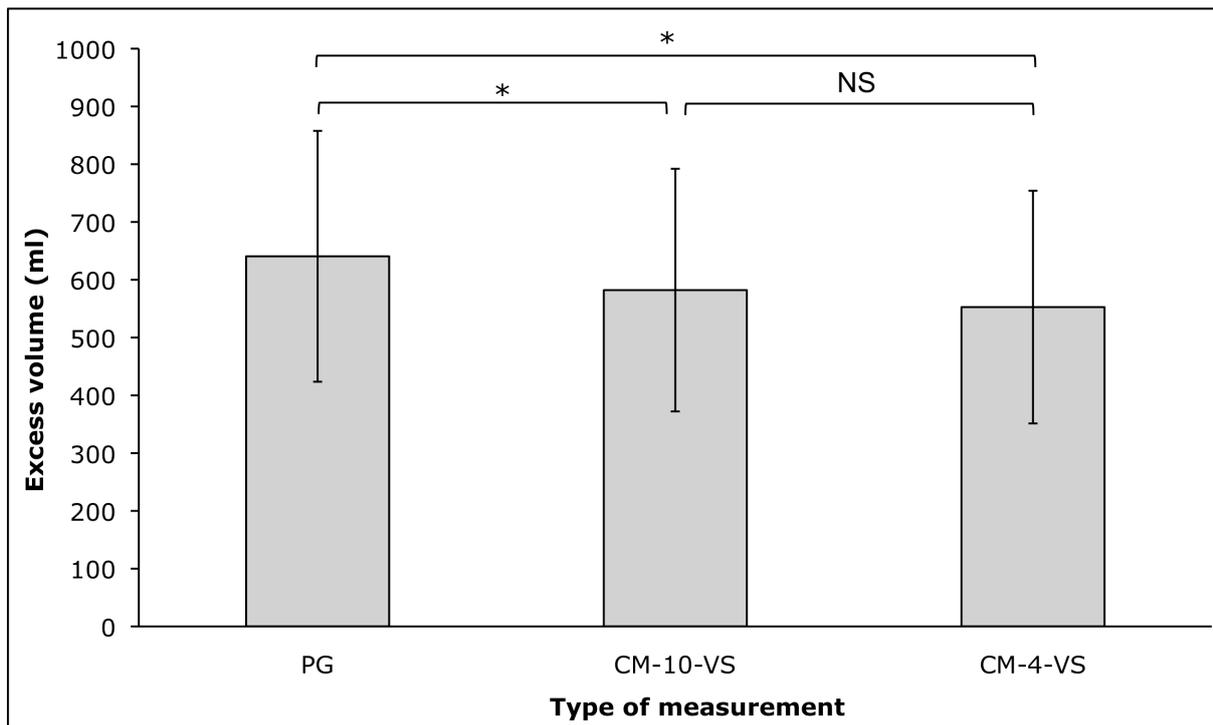Figure 3. Measuring the arm volume with circumference measurements.

Figure 4. Mean (±SD) volumes and type of volume measurement. There was no significant difference between CM-10-VS and CM-4-VS, the two volume measurement methods based on circumference (CM-10-VS and CM-4-VS).
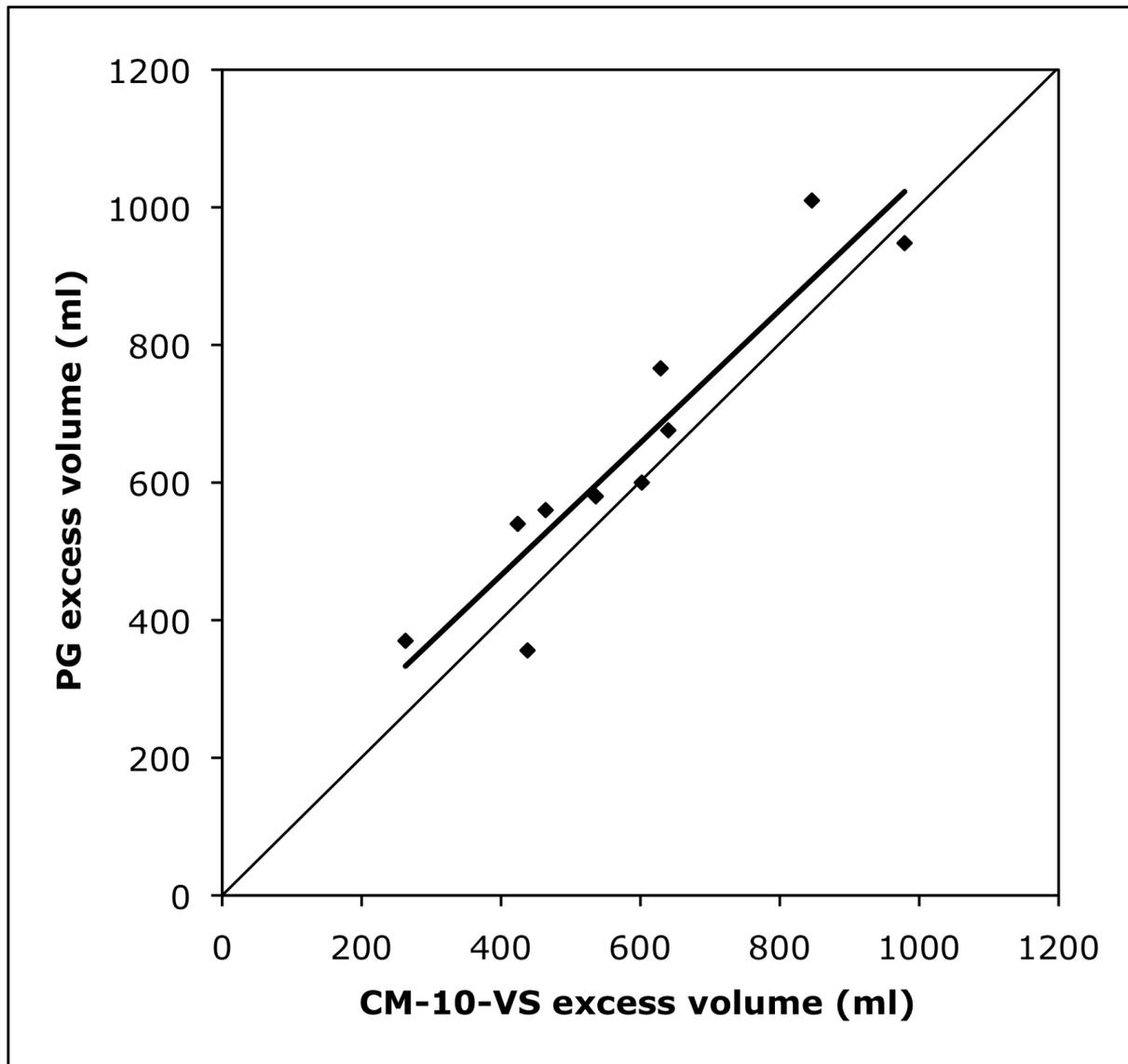
Figure 5. Regression analysis of the mean excess arm volume measured by plethysmography (PG) and circumference measurements using 10 volume segments (CM-10-VS excess volume) [$r = 0.932$, $\beta = 0.963$ (95% CI: 0.657–1.269), $P = 0.0001$].
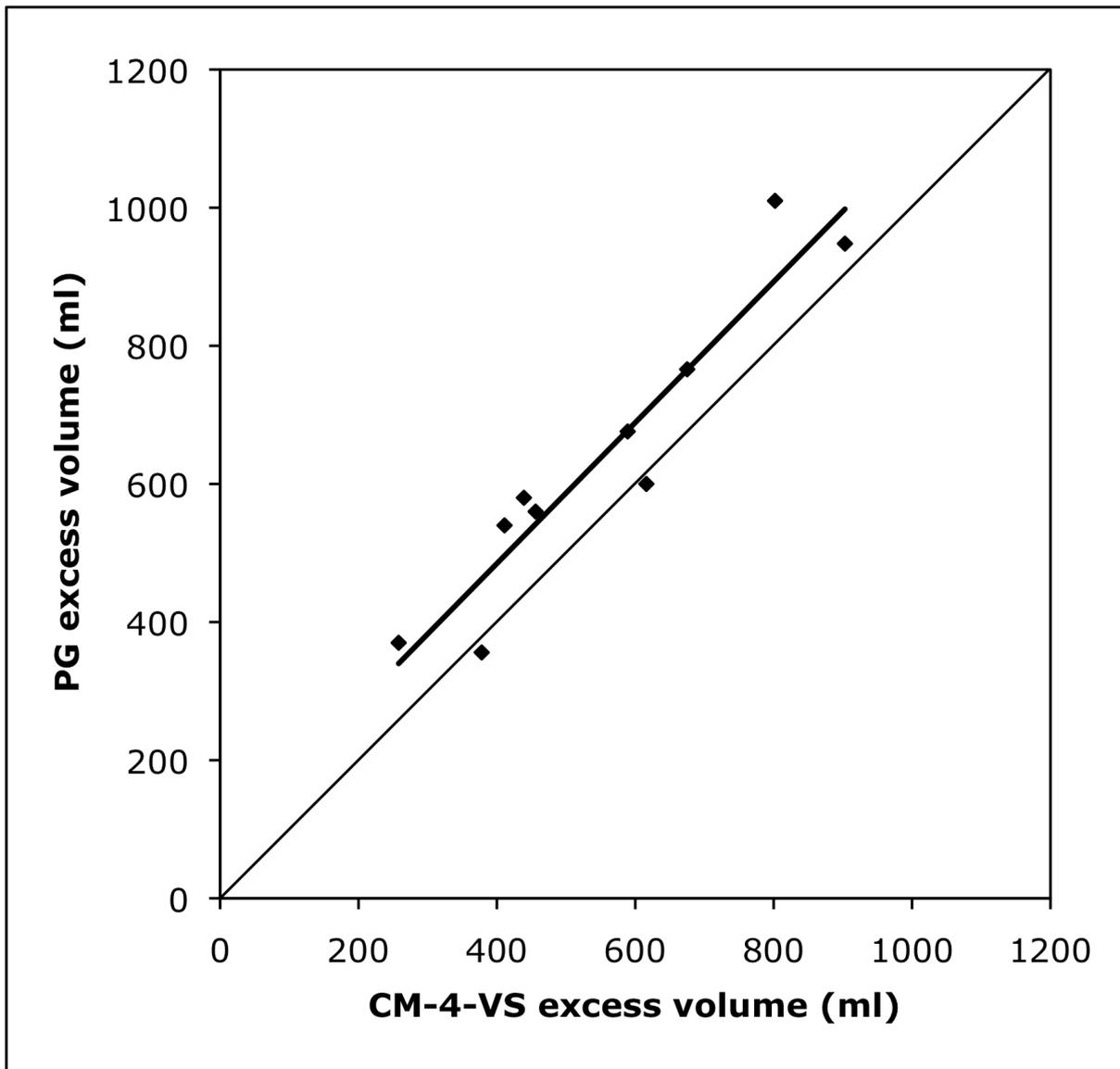
Figure 6. Regression analysis of the mean excess arm volume measured by plethysmography (PG) and circumference measurements using 4 volume segments (CM-4-VS excess volume) [$r = 0.946$, $\beta = 1.020$ (95% CI: 0.736–2.304), $P = 0.0001$].
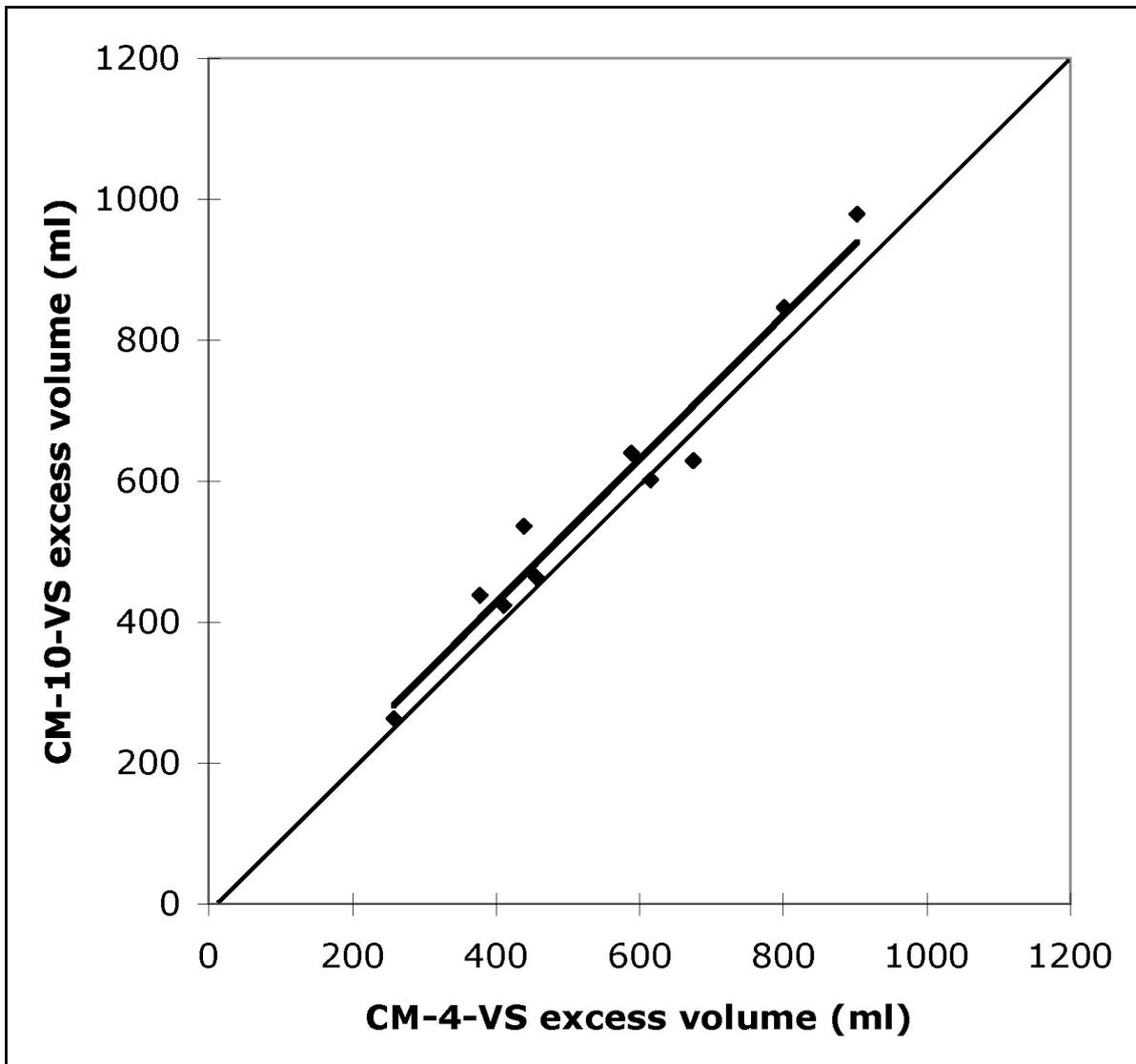
Figure 7. Regression analysis of the mean excess arm volume measured by circumference measurements using 10 (CM-10-VS excess volume) and 4 (CM-4-VS excess volume) volume segments [$r = 0.978$, $\beta = 1.020$ (95% CI: 0.843–1.197), $P = 0.0001$].