Volume Measurements and Follow-Up

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Key Points

- Outcomes of surgical treatment of lymphedema very seldom present results as excess volume or excess volume reduction. Instead circumference measurements, taken at random sites along the extremity, are used making it very difficult to estimate the true outcome as well as to compare various studies.
- Volume measurement, either using plethysmography or based on circumference measurements, is an easy and quick method to objectively assess treatment outcome and to increase the scientific impact when presenting results.

Introduction

Measurement of extremity volumes with plethysmography or indirect via circumference measurement is essential for assessing the size of the lymphedema and for treatment monitoring. It is important that both the normal and diseased limb is measured in exactly the same way at all time points to eliminate natural volume variations. The normal arm volume variations are between 2 and 13 % in healthy individuals. The dominant arm is usually about 1.5 % larger [1]. Lymphedema is usually defined as a relative extremity volume difference > 10 percent (the edematous extremity is 10 % larger than the normal) [2, 3]. Both plethysmography and circumference measurements are useful and show satisfactory validity and reliability [4–9], plethysmography is recommended if only one method is used [10].

Volume Measurements Using Plethysmography

The most reliable way to measure the volume of an extremity is plethysmography according to Archimedes' principle, i.e., the limb is immersed in a water bath and the drained water is weighed [1–11]. The weight in grams equals the volume in milliliter and also includes the hand and foot volume. For description of the volume meter see Figs. 11.1 and 11.2.

For both the arm and leg volume meter it is important that the draining pipe is be placed high enough so that the entire limb can be measured. The diameter of the draining hose should be large so that the water can flow quickly. It is important that the limb is immersed into the volume meter at exactly the same depth each time.

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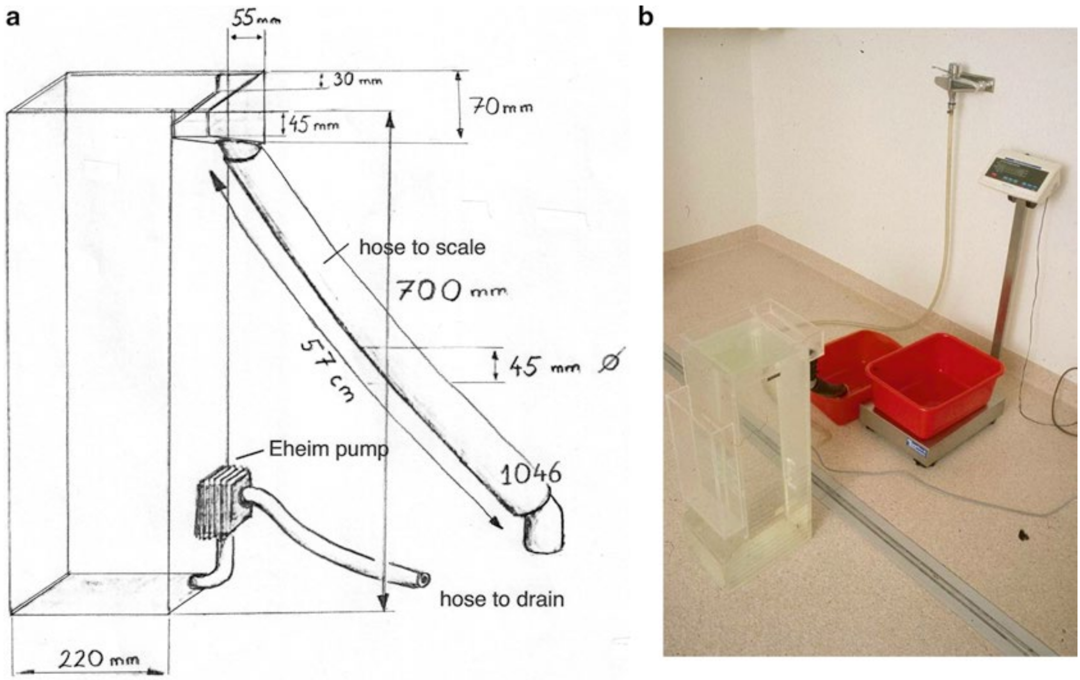

Fig. 11.1 (**a**) Arm volume meter. Figures in millimeter. (**b**) The clinical setup

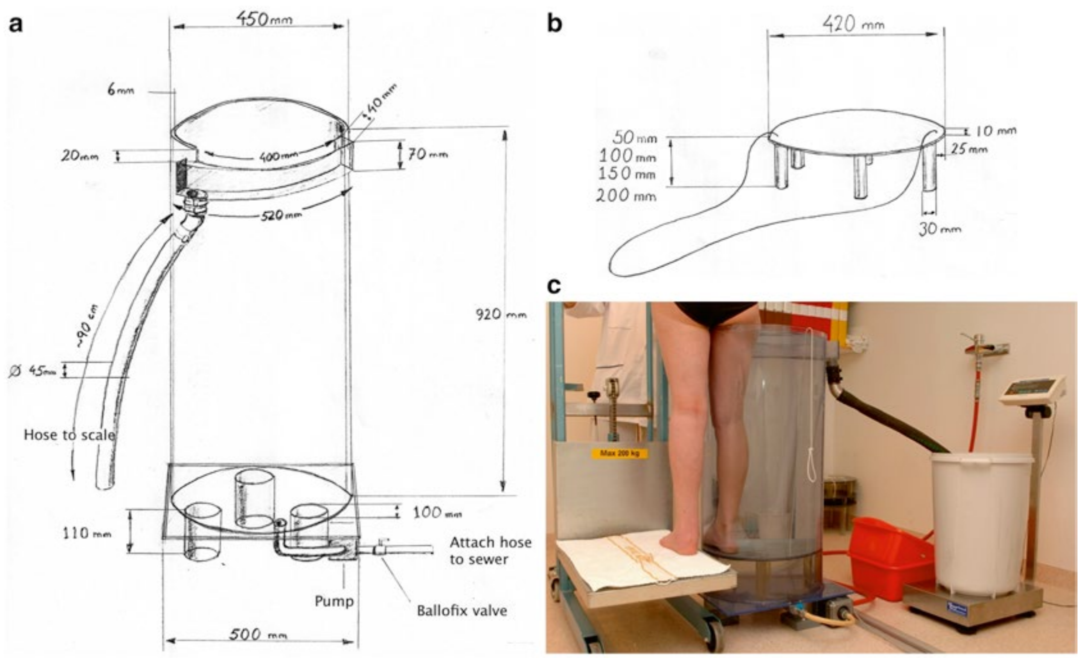

Fig. 11.2 (**a**) Leg volume meter. Figures in millimeter. (**b**) Leg volume meter. Spacers to compensate for various leg lengths. Figures in millimeter. (**c**) The clinical setup

Arm Volume Meter (Fig. 11.1)

The hose is connected to a standard faucet with a threaded bayonet mount and the volume meter is filled with water through a hose at the bottom of tank. The arm is brought down into the volume meter with the palm against the wall to avoid surge. The fingers are held outstretched and brought down until the tip of the middle finger reaches the bottom. Wait a few seconds to allow the water to flow out. There are gradation lines with 1-cm intervals for patients who do not reach down to the bottom of the volume meter. Measurements can be reproduced from time to time by noting the distance between the volume meter's bottom and the tip of the middle finger. The drained water is collected in a plastic tray (Orth Plast, for example, model 101-8: 40 cm× 34 cm×16 cm), which holds about 17 L. To empty the volume meter the hose is led down a drain in the floor or to a sink so the water can drain. An electric pump accelerates the runoff (Eheim 1046, Eheim, http://www.eheimparts.com). A drawing of a volume meter is shown in Fig. 11.1. The scale should have an accuracy of 5 g (digital max 30 kg/5 g). The volume meter has an average measurement error (CV%) of 0.24.

Leg Volume Meter (Fig. 11.2)

To compensate for different leg lengths, different spacers are put into the volume meter so that the entire leg volume can be measured up to the crotch. The measuring cylinder's height minus the leg length = the height of the spacer. An electric pump accelerates the runoff when emptying (Eheim 1060, Eheim, http://www.eheimparts.com). To hoist the patient a commercially available "lift" (Santo Lift SC 200, PMH International AB, http://www.pmh.se) is used. The water is collected in a large plastic laundry basket (Idealplast; model 0519; 33 cm×55 cm), which holds about 40 L (Fig. 11.2).

Volume Measurements Based on Circumference Measurements

Another method is circumference measurements on well-defined distances along the limb. Circumference measurements also provide information of the localization of the swelling. Hand and foot volumes cannot be calculated. To only make single circumference measurements (for example the middle of the upper arm, elbow, middle of the forearm) is not adequate either for clinical use or scientific study.

Volume measurements based on plethysmography or circumference measurements are useful and show satisfactory validity and reliability [4–9], plethysmography is recommended if only one method is used [10].

How Volumes Are Calculated Using Circumference Measurements

The circumferences of the limb measured every 4 cm along the limb. The volume of each segment is calculated according to the formula of the truncated and added together to get the limb volume (Fig. 11.3):

$$V = \frac{1}{3} \times \pi \times h \times \left(r_1^2 + r_2^2 + r_1 \times r_2 \right)$$

You need:

- A long ruler to mark every the 4 cm
- Marker pen (eyeliner pen)
- Narrow tape measure for circumference measurements
- Protocol.

How to measure:

- Arm lymphedema: The patient sits on a chair with the arm straight and abducted 90 ° on a table
- Highlight the 0 point in the wrist level
- The tape is placed around the extremity distal to each mark
- Read the circumferences measured and record

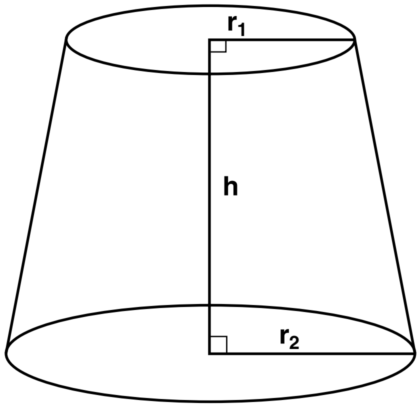

Fig. 11.3 Truncated cone segment. *H* height of the cone. r_1 radius at upper end of the segment. r_2 radius at lower end of the segment

- Leg lymphedema: The patient sits with the hip flexed at 90° with extended knee and foot in 0-position.

The measurement programs for arms and legs can be downloaded from: https://lu.box.com/s/9abvigfbx2rw7afgk9kz or by contacting the first author.

Other Methods

The following methods are not used routinely, but mainly for research purposes.

Perometry

This is an *optoelectronic measuring* method using a square frame with multiple perpendicular light beams. The frame is moved along the limb and the cross-sectional area is calculated continuously and thereby the volume. The equipment is expensive, but the method is accurate and fast [12]. Foot and hand volume are not measured [13, 14].

Bioelectric Impedance (BIS)

Extracellular fluid can be measured by bioelectrical impedance, which is recorded with a low current with different frequencies, transmitted through the tissue [15]. The method is particularly useful for diagnosing early lymphedema of the arm after breast cancer treatment [16].

Local Tissue Fluid, Tissue Dielectric Constant (TDC)

Tissue fluid may be measured by means of electromagnetic waves transmitted via a measuring head, which is set against the skin. The instrument measures a few millimeters into the skin and a constant (tissue dielectric constant), directly proportional to the tissue fluid content, is calculated. The method is useful for measuring tissue water anywhere in the body where the skin is not too close to the skeleton. The method has been used to measure edema in the extremities [17], legs [18, 19].

Other methods include *computed tomography* (CT) [20] and *magnetic resonance imaging* (MRI) [21].

Volume Calculations

A large number of computational methods have been presented for reporting treatment results [5, 7, 8]. The *excess volume* of a unilateral lymphedema is calculated as the difference between the edematous and the contralateral healthy extremity.

The *absolute excess volume* (volume of the affected limb – volume of the unaffected limb) of a lymphedema [22, 23] together with the *relative value* in percent (affected limb/unaffected limb × 100) gives optimal information before and after treatment. The relative value provides information about the extent of the edema [1, 10]. The same absolute excess volume provides greater relative value (swollen extremity/healthy extremity) in a skinny person as compared to a corpulent [1, 10].

Absolute Excess Volume and Percentage Reduction

Edematous arm (EA), Normal arm (NA), Before treatment (bt), After treatment (at).

	EA	NA	Excess volume	Excess volume reduction (%)
bt	5,000 ml	2,000 ml	Δ3,000 ml	
				67 %
at	3,000 ml	2,000 ml	Δ1,000 ml	

By measuring the normal arm at the same time as the edematous arm one takes into account the daily variations in arm volumes as well as weight gain or loss. It is very important that this is done at every time when volumes are measured.

$$\frac{(EA_{bt}-NA_{bt})-(EA_{at}-NA_{at})}{(EA_{bt}-NA_{bt})}\times 100=\frac{(5,000\text{ ml}-2,000\text{ ml})-(3,000\text{ ml}-2,000\text{ ml})}{5,000\text{ ml}-2,000\text{ ml}}\times 100$$

$$=\frac{3,000\text{ ml}-1,000\text{ ml}}{3,000\text{ ml}}\times 100=\mathbf{67}\ \%$$

Follow-up controls

	EA	NA	Excess volume	% Excess volume reduction
bt	5,000 ml	2,000 ml	Δ3,000 ml	
at1	4,000 ml	2,200 ml	Δ1,800 ml	$\frac{3,000\text{ ml}-1,800\text{ ml}}{3,000\text{ ml}}\times 100$ $=\mathbf{40}\,\%$
at2	3,000 ml	1,800 ml	Δ1,200 ml	$\frac{3,000\text{ ml}-1,200\text{ ml}}{3,000\text{ ml}}\times 100$ $=\mathbf{60}\,\%$
at3	2,000 ml	2,000 ml	Δ0 ml	$\frac{3,000\text{ ml}-0\text{ ml}}{3,000\text{ ml}}\times 100$ $=\mathbf{100}\,\%$

The same calculation applies also for a leg.

In bilateral lymphedema the excess volume cannot be determined. Instead the change in volume, also in percent, for each limb is calculated, i.e.,

$$\left(\frac{EA_{bt}-EA_{at}}{EA_{bt}}\right)\times 100=\left(1-\frac{EA_{at}}{EA_{bt}}\right)\times 100.$$

When scientific material is presented, the mean excess volume for all patients at baseline is calculated, as well as at follow-up. The percentage reduction for each patient is calculated and the mean percent edema reduction for all patients is calculated at follow-up.

The Relative Value of the Excess Volume

The excess volume can also be calculated in relation to the normal arm as a ratio, i.e., edematous arm/normal arm.

	EA	NA	Ratio
bt	5,000 ml	2,000 ml	2.5
$\frac{EA_{bt}}{NA_{bt}}=\frac{5,000\text{ ml}}{2,000\text{ ml}}\times 100=2.5$			
at	3,000 ml	2,000 ml	1.5
$\frac{EA_{at}}{NA_{at}}=\frac{3,000\text{ ml}}{2,000\text{ ml}}\times 100=1.5$			

The absolute excess volume is not always sufficient to describe a lymphedema. The same absolute excess volume of 200 ml (difference between the edematous arm and the normal arm) in a lean and in a corpulent person results in 10 % relative excess volume in a lean subject as opposed to 5 % in a corpulent subject.

Lean subject			Corpulent subject		
EA	NA	Excess volume	EA	NA	Excess volume
2,200 ml--2,000 ml			4,200 ml--4,000 ml		
= 200 ml			= 200 ml		

Excess volume in percent:

$$\frac{200\ \text{ml}}{2{,}000\ \text{ml}} \times 100 = 10\ \% \quad \frac{200\ \text{ml}}{4{,}000\ \text{ml}} \times 100 = 5\ \%$$

Potential Sources of Errors

Potential Sources of Error

A common source of error is when the normal limb volume is measured only at baseline or not at all. This leads to incorrectly calculated values when the normal limb increases or decreases in volume [11].

Diurnal variation and weight loss or gain are sources of error, especially in patients with a small lymphedema.

Examples

Example of calculations of percent excess volume reduction when even the *normal* limb volume *decreases* (see Table 11.1).

The percentage reduction is calculated correctly when the normal limb volume is measured both before treatment and at follow-up (*). The left side of the table shows data from one arm while the right shows data from a leg. Note that if the initial normal limb volume is used at all subsequent measurements incorrect values are achieved. In the example of the arm an incorrect reduction of 53.9 % is calculated instead of 32.5 %, which is the correct excess percentage reduction. In the example of the leg an erroneous reduction of 91.2 % is calculated instead of the correct value of 7.3 % (see Table 11.1).

Example of calculations of percent excess volume reduction when even the normal limb volume *increases* (see Table 11.2):

The percentage reduction will be calculated correctly by the normal limb volume measured

Table 11.1 Example of calculations of percent excess volume reduction when even the *normal* limb volume *decreases* [11]

	Arm			Leg		
	Extremity volume			Extremity volume		
	Before	Follow-up	Follow-up*	Before	Follow-up	Follow-up*
Edematous extremity	4,798	4,297	4,297	9,441	8,366	8,366
Normal extremity	**3,869**	3,670	**3,869**	**8,262**	7,273	**8,262**
Excess volume	929	627	428	1,179	1,093	104
% Reduction		32.5 %	53.9 %		7.3 %	91.2 %
		Correct	Incorrect		Correct	Incorrect

The percentage reduction is calculated correctly when the normal limb volume is measured both before treatment and at follow-up (*). Bold numbers represent the use of the same volume of the normal extremity both at initial and final measurement, which is incorrect

Table 11.2 Example of calculations of percent edema reduction when even the *normal* limb volume *increases* [11]

	Arm			Leg		
	Extremity volume			Extremity volume		
	Before	Follow-up	Follow-up*	Before	Follow-up	Follow-up*
Edematous extremity	3,784	3,212	3,212	12,268	9,681	9,681
Normal extremity	**2,500**	2,599	**2,500**	**7,168**	7,877	**7,168**
Excess volume	1,284	613	712	5,100	1,804	2,513
% Reduction	52.3 %	44.5 %		64.6 %		50.7 %
		Correct	Incorrect		Correct	Incorrect

The percentage reduction is calculated correctly whem the normal limb volume is measured both is measured both before treatment and at follow-up (*). Bold numbers represent the use of the same volume of the edematous extremity both at initial and final measurement, which is incorrect

both at initial measurement and the final measurement (*). The left side of the table shows data from one arm while the right shows data from a bone. Note that if the normal limb initial measured value is used all the time to get the wrong values. In the example on an arm improperly obtained an edema reduction of 44.5 % instead of 52.3 %, which is the correct edema reduction. In the example on one leg got an error reduction of 50.7 % instead of the correct 64.6 % (see Table 11.2).

Conclusion

Volume measurement should be used when presenting outcomes of lymphedema treatment.

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