ORIGINAL ARTICLE

Variation in Results of Volume Measurements of Stumps of Lower-Limb Amputees: A Comparison of 4 Methods

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ABSTRACT. de Boer-Wilzing VG, Bolt A, Geertzen JH, Emmelot CH, Baars EC, Dijkstra PU. Variation in results of volume measurements of stumps of lower-limb amputees: a comparison of 4 methods. Arch Phys Med Rehabil 2011;92: 941-6.

Objective: To analyze the reliability of 4 methods (water immersion, computer-aided design [CAD] photometric method, CAD hand scanner, and circumferential measurements) for stump volume measurement in transtibial amputees.

Design: Repeated measurements.

Setting: General community, ambulatory care.

Participants: Transtibial amputees (N=26; mean age ± SD, 58.7±11.0y).

Interventions: Stump volume of patients with an amputation was measured on 2 occasions, each consisting of 2 sessions. In each session, stump volume was measured by 2 observers using each of the 4 methods. Sequence of observers and measurement methods was determined randomly.

Main Outcome Measure: Repeatability coefficients, as a measure for reliability, for each method were calculated, as well as variance components to estimate the influence of measurement conditions on stump volumes measured.

Results: Repeatability coefficients varied from 129mL CAD hand scanner to 158mL CAD photometric method. Error variance contributed 12% to the total variance. Methods contributed 36%, method-amputee and occasion-amputee interactions contributed both 25% to the error variance.

Conclusions: Repeatability coefficient was lowest for the CAD hand scanner, which indicates the best reliability. Substantial differences existed in stump volumes measured between the 4 methods.

Key Words: Amputation; Rehabilitation.

A STABLE STUMP VOLUME is a necessary condition for prosthesis fitting.[1] When the prosthesis is fitted too early after amputation, the stump volume may still diminish because of the decrease of postsurgical swelling.[2] As a result, the fitted socket becomes too large in the short term. If the prosthesis is fitted too late, muscle atrophy and patient deconditioning may occur thus lengthening the rehabilitation process unnecessarily. Therefore, to estimate the optimal time for prosthetic fitting, change in stump volume has to be measured accurately. Different methods to measure stump volume have been developed and applied, for example water immersion,[3-5] surface scanners,[5-7] computed tomography (CT),[6,7] computer-aided design (CAD) systems,[8-11] and circumferential measurements.[4,5,12-14] Most of the research into reliability of these methods has been performed on models of stumps[4,6,8,11,13,15] or on three-dimensional (3D) mathematical models, like a cylinder, column, or square column.[8,10,15] By making use of stump models, factors that might influence reliability (measurement results) are not taken into consideration (eg, shifting of position of the amputee,[16] variation in stump volume,[6,17] observer-amputee interaction, and muscle contraction). Thus, analyzing reliability on stump models may result in better reliability than when it would have been tested on amputees. Reliability has been analyzed on amputees in relation to using the optical surface scanning, spiral CT, and water immersion methods. However, these methods are not practical for daily use because they are not portable, are expensive, or require the ability of an amputee to stand for a longer period of time on the sound leg. Prerequisites for a method to measure stump volume clinically are: reliability, safety, and portability for clinical application. In a recent study, analyzing 5 different clinical measurement systems to measure volume of transtibial stump models, it was found that the reliability of a CAD hand scanner was best.[4] We hypothesize that repeated measurements of volumes of stumps of patients who had a transtibial amputation are also most reliable when using the CAD hand scanner than other clinical measurement systems.

METHODS

Population

Patients were recruited from a list of clients from a regional orthopedic workshop (OIM orthopedie, Assen, The Netherlands). Inclusion criteria were: (1) unilateral transtibial amputation; (2) willingness of the amputee to participate in the study; and (3) availability on measurement days. Exclusion criteria were: (1) large changes in stump volume during the day and less than 1 year postamputation, to diminish influence of

List of Abbreviations

ANOVA	analysis of variance
CAD	computer-aided design
CT	computed tomography
3D	three-dimensional

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actual change in stump volume on reliability; (2) not able to stand on 1 leg with minimal support for at least 1 minute; and (3) patients with an amputation under the age of 18. A sample of 32 patients with an amputation was recruited based on the assumption that variance components become stable when 30 participants are measured repeatedly. Informed consent was given by each patient with an amputation. This research was approved by the Medical Ethical Committees of the University Medical Center Groningen and the Isala Clinics Zwolle, both in The Netherlands.

Selection of Measurement Methods

By interviewing multiple experts (physicians, orthopedic technicians, manufacturers), 4 methods were selected to investigate in our study: water immersion; Design TT (CAD photometric method)[a]; Omega Tracer (CAD hand scanner)[b]; and circumferential measurements. These methods were selected based on the criteria mentioned in the introduction. Although water immersion does not comply to all criteria, we chose to use it in our study because it is often considered the criterion standard.[8,9]

Experimental Design

Every patient with an amputation was measured on 2 occasions, each consisting of 2 sessions. In each session, both observers measured the patient with an amputation with each of the 4 met the methods. Thus, a total of 32 measurements were performed on each patient with an amputation. The sequence of observers and measurement methods was determined randomly using multiple sets of sealed envelopes for each occasion and session. All measurements were performed between August 2007 and May 2008.

To enhance measurement procedures, 3 dots (reference points) were placed on the stump with a water-resistant marker. Two dots were placed at the medial and lateral knee joint, respectively. The third dot was placed at the anterior side of the stump at the same level as the medial and lateral dot, while the patient was in sitting position with the knee extended. The dots were placed at the beginning of each measurement occasion and were not removed during the occasion.

Description of the Measurement Methods

Water immersion. A glass cylinder with a diameter of 15cm, filled with water to the brim, was placed level on a hand-operated elevator. The patients with an amputation placed the distal part of their stump in the cylinder, and the elevator raised the glass cylinder until the reference points touched the water surface. After the reference points touched the water surface, the glass cylinder was lowered and the stump was removed from the cylinder. Stump volume was estimated by refilling the glass cylinder to its original level by using a measuring cylinder with a 10mL interval scale. No stocking was used during this measurement procedure.

Design TT. The Design TT system is designed to create a socket for prostheses for patients with a transtibial amputation. With the use of 2 digital photographs, 1 from the anterior side and 1 from the lateral side, this system constructs a digital socket. Normally, before making the photographs, the patellar tendon is marked, a thin white stocking is placed over the stump, and a calibration device is placed on the stump. The software allows calculation of the socket volume (not the original stump volume) on each height distal from the patella tendon. Because the anterior dot, used in the current study, lies generally proximal of the patella tendon, and thereby it would not be possible to estimate the volume distal of the anterior dot, the Design TT system was used in a slightly alternative way, by using the anterior dot as a reference point instead of the patella tendon. In order to make better comparison with other methods, photographs were taken with the knee extended instead of the advised 15° flexion.

Omega Tracer. The Omega Tracer system is designed to create orthoses and prostheses for the human body. This handheld scanner projects laser beams on the stump and makes multiple digital photographs while scanning the stump, which was fit with a thin white stocking with reflective dots positioned randomly (1 dot per 2–4cm^2). With the use of these pictures, a software program creates a 3D view of the body part. For our study, elevated markers were placed over the reference points in order to recognize them on the 3D view. The volume distal of the 3 dots was calculated by the system.

Circumferential measurements. Circumferential measurements were made using a Gulick measuring tape (model 258-J00305, 1-mm calibration)[c], which has a tensioning device, in order to enable the same amount of tension during each measurement. Prior to the measurements, a thin white stocking was placed over the stump to protect the skin of the stump against frequent marking and cleaning. Circumference was measured at 4-cm intervals, starting 4cm proximal from the distal end of the stump. The most proximal measurement was the measurement through the 3 dots. The 4-cm intervals were indicated on the medial, lateral, and anterior side of the stump with the use of markers. The markers were replaced for each measurement. The volume of the stump was calculated using the following formula, which is adjusted from the formula described by Sitzia[18] for measuring the volume of the arm in patients with lymphedema by adding up the volumes of each frustum:

$$V = 1/3\pi * \left[h_1\left(r_1^2 + r_1 * r_2 + r_2^2\right) + h_2\left(r_2^2 + r_2 * r_3 + r_3^2\right) + ... + h_{z-1}\left(r_{z-1}^2 + r_z * r_{z-1} + r_z^2\right)\right] + 1/2\pi r_z^2 h_z$$

in which V stands for volume of the stump, r stands for the radius of the frustum (most proximal measurement at location 1 and most distal measurement at location z), and h stands for height of the frustum. For a more accurate approach to the real volume of the stump for the distal end, the formula for a paraboloid ($1/2\pi r^2 h$) was used instead of using the formula for a frustum. The radius of the frustrum/paraboloid is calculated by the following formula: $r = c/2\pi$, in which c is the circumference.

Statistical Analysis

Reliability. As a measure for reliability, repeatability coefficients were calculated using the square root of the residual variance, for each method using 1-way analysis of variance (ANOVA) with patients (with an amputation) as the factor.[19] The repeatability coefficient is calculated as $1.96*\sqrt{2}*\sqrt{}$ residual variance.

Variance components were calculated of all measurement conditions and their 2-way interactions: patient (with an amputation), observer, method, session and occasion using ANOVA, and type III sum of squares. Negative variance components were set to zero. Error variance was calculated as the sum of all variance components minus the variance attributed to the patient with an amputation. The contribution of the measurement conditions to the error variance was expressed as a percentage. To analyze the