USE OF A LASER SCANNING SYSTEM TO MEASURE LIMB VOLUME IN CHRONIC EDEMA

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INTRODUCTION

Chronic edema and wounds of the lower limbs are frequent complications of immobility. There are many ways to assess disease progress in chronic edema. These include volume measurement, mechanical testing to determine dermal fibrosis, and imaging studies.[1] Although mechanical testing is often the best indicator of progress, volume measurement of the affected limb is the most common means of monitoring the effects of treatment. The gold standard for measuring volume is water displacement, but estimates of volume are typically obtained from multiple circumferential measurements. This method is awkward, tedious, and produces variable results. This is especially true for immobile individuals or when attempting to measure areas of the body with irregular shapes.[2]

A hand-held laser scanner currently being used to provide accurate measurements of body segments for fabrication of orthoses and prostheses is one of the possible replacements for measurements obtained with a tape measure. *Laser scanning* creates a three dimensional computer model of the body part being scanned which is typically imported into CAD/CAM programs.[3] This model can also be used to assess the overall size, shape and volume of the limb. The investigators have assessed this technology as a means of obtaining trunk and lower limb volume for a future study. In that study, we intend to utilize the laser scanning method in a home environment to assess the clinical efficacy of a chronic edema self-care telerehabilitation program for immobile persons.

METHODS

Seven healthy subjects were recruited for the study. First, the subjects were measured using two separate water volumeters. The first tank measured the subject's leg and foot up to a position just below the knee. The second tank measured the subject only up to a point below the ankle. The ankle was placed at a 90-degree angle, blocks were inserted into each tank to ensure that the water level reached approximately the same place each for each subject. The water level was marked on the subject's limb with ink for each immersion. Each measurement was taken three times.

The subjects were then instructed to put on a white stocking to have the segments of the leg and foot (referenced to the water level line) scanned using the Insignia™ laser scanner (Hanger Prosthetics & Orthotics, Austin, TX). An image of the scanner can be found in figure 1. The scanner was operated operated by an experienced orthotist-prosthetist practitioner. The insignia consists of a laser output array with an attached camera to record the laser position, as well as a position sensor affixed to the limb to correct for subject movement. The subject's foot was placed on a specialized plexiglass stand with the ankle at 90 degrees. The lower leg and foot of each subject was scanned three times. The computer analyzed each set of points to create an outline of the limb with the water level points marked on the computer model.

Figure 1: The Insignia™ laser scanning system[4]

A point cloud file was exported and analyzed using Microsoft Excel as a frustum, where:

$$V = \frac{h}{3}\left(B_1 + B_2 + \sqrt{B_1 B_2}\right) \quad (5)$$

The measurements of both limb segments were analyzed using Pearson's correlation coefficient between the water volumetry measurement and the laser scanning volume.

RESULTS

The summary of the data, as well as the comparison between the laser scanner and the water volumeter can be found in Table 1. The results of the study showed a high correlation between measurements for the limb segments. The measured volumes for the laser scanner had a normalized standard deviation of less than one percent for the leg and approximately 6 percent for the foot segment. For the leg, the average difference between the measured tank and the insignia was 11.3 mL or 0.87% normalized volume with a Pearson's Correlation coefficient was 0.985 for the leg segment. For the foot, the difference was 119 mL or 11% normalized volume with a Pearson's correlation coefficient of 0.962.

DISCUSSION

Although there are a variety of methods available for measuring volume, many of these methods are cumbersome, difficult to use accurately, or inappropriate for irregular body shapes and persons with mobility impairments. Taylor et al. (2006) found that, for arm volumes, circumferential measurements yielded variability between 1.5 and 4.9% of total volume with a correlation coefficient of 0.98.[6] Our method performed much better by comparison, especially on the leg segment, which correlates to this study). Additionally, the variability of taking circumferential measures is likely to be much higher when examining the lower limb in immobile persons due to the difficulty in positioning.

The Insignia™ calculates volume using the same mathematical principles, by creating circumferences with smaller intervals and without touching the skin. In order to minimize movement (and maximize accuracy), some apparatus must be used to stabilize the body segment being measured. In our study, the foot was placed on a stand that had plexiglass panels to allow the scanner to measure the bottom of the foot. However, the stand interfered with our ability to make a truly accurate measurement of the foot segment.

Additionally, the investigators did not confirm reliability of the device between multiple technicians. For standard circumferential measurements, precise positioning of the tape and tension applied both affect the outcome of each individual measurement. Although the anatomical landmarks must be carefully marked, no positioning is required to take the measurements. Additionally, the real-time results displayed on the computer screen allow the researcher or clinician to immediately see if the scan is rendered properly, that there are no obvious miscalculations, and that all areas of the scan match the contours of the subject's limb.

CONCLUSIONS

The laser scanning system performed better than current clinically used measurement protocols. Bearing in mind the specific cautions mentioned above, it is suitable for assessing volume in any patient, and is particularly suitable for measuring patients outside of a clinical setting.

Limb Segment	Laser Scanner		Water Volumetry		Comparison		
	Average Volume	***Normalized St. Dev***	***Average Volume***	***Normalized St. Dev***	***Difference***	***Normalized Difference***	***Correlation Coefficient***
Leg	1893mL	0.85%	1882mL	1.5%	11mL	0.87%	0.985
Foot	1198mL	6.1%	1079mL	1.3%	119mL	11%	0.962

Table 1: Summary of volumetry measurements

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