An instrument for monitoring stump oedema and shrinkage in amputees

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Abstract

A new system for measuring the cross-sectional area profiles of amputation stumps and whole limbs has been designed at the Amputee Research Centre. The instrument consists of a cylindrical tank supported on an elevator. The tank is raised to the height of the amputation stump and filled with water. A graph of the cross-sectional area profile of the amputation stump is generated by a mini-computer as the elevator descends. The cross-sectional area (A) is calculated from the expression:

\[ A = \frac{dH_w}{d(H_w + H_e)} \times A_c \]

where

- \( H_w \) = height of water in the tank
- \( H_e \) = height of the elevator
- \( A_c \) = a constant, related to the size of the measuring tank.

This paper describes the instrument, which may find application in many other areas where there is a need to study shape.

Introduction

A new clinical system for measuring the cross-sectional area profiles of amputation stumps and whole limbs has been designed at the Amputee Research Centre. This instrument was developed in order to attempt to answer three questions:

1. Can the time taken for stump shrinkage to be completed be accurately predicted and delays or mistakes in definitive fitting minimized?
2. What is the optimum method to use to accelerate stump shrinkage?
3. To what extent does a mature amputation stump fluctuate in volume?

This instrument is based upon a novel concept and may find application in many other areas where there is a need to study body shape (Drillis et al. 1964). The results of the amputee study will follow in two years time. In the

Fig. 1. Diagrammatic representation of the principles of the instrument, where \( H_w \) = height of the water in the tank, \( H_e \) = height of the elevator.

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meantime it is felt that a paper describing the instrument and its use would be of value.

The instrument

A cylindrical tank is supported on an elevator (Fig. 1). The tank is raised on the elevator to fit the amputation stump and filled with water at a controlled temperature. As the tank is lowered so the water level in the tank is caused to decrease since the water surface is being withdrawn from the amputation stump. The rate at which the depth of water is decreasing at any moment in time is proportional to the cross-sectional area of the amputation stump that at that moment in time corresponds to the water surface. Evidently when the end of the stump is reached the rate of decrease in the depth of the water in the tank becomes zero. The depth of the water in the tank is $H_w$ and the height of the elevator is $H_e$. The cross-sectional area at any moment in time during this measuring process can therefore be calculated according to this simple equation:

$$A = \frac{dH_w}{d(H_w + H_e)} \times A_c$$

where the constant $A_c$ depends upon the cross-sectional area of the measuring tank used.

The instrument is shown in Figure 2. The elevator is in a rigid frame and is hydraulically driven to provide a smooth, vibration free movement. The water filling and emptying is solenoid valve operated to increase the speed and ease of operation. Simple adjustable supporting pads and an adjustable arm rest are used to steady the patient. An overhead safety harness is also fitted.

The height of the elevator is transduced by a potentiometric displacement transducer (R.I. Control Model 4040). The method of measuring the depth of the water is shown in Figure 3. A precisely machined cylinder is suspended in a manometer from an extension spring. Changes in the depth of the water in the measuring tank cause equal changes in the height of water in the manometer tube. The buoyancy force exerted upon the cylinder changes since it is proportional to its depth of immersion. The resulting change in length of the extension spring is transduced by means of a linear voltage displacement transducer.

The measurement process is controlled by a system based on the Tektronix 4051 mini-computer. The calculation involves a differentiating process. A "least squares" technique is employed to limit the noise sensitivity of this
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A variety of different forms of graphical and numerical output have been employed. The results of each test are stored on magnetic tape so that they can be recovered for the sake of comparison at any time.

**Instrument accuracy**

A calibration shape made up of 4 cylinders of 5, 10, 15 and 20 cm in diameter was measured using the 25 cm diameter measuring tank on the instrument. This shape is shown in place in

<table>
<thead>
<tr>
<th>Actual value (cm³)</th>
<th>Mean measured value (cm³)</th>
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<tr>
<td>19</td>
<td>19</td>
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<tr>
<td>77</td>
<td>76</td>
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<td>176</td>
<td>174</td>
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<tr>
<td>311</td>
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</table>

Table 1. A comparison of the mean result of 12 measurements of a calibration shape with the actual cross-sectional area measured using a micrometer.

Figure 2. Table 1 shows a comparison of the mean result of 12 measurements with the actual cross-sectional area measured using a micrometer. Very close agreement was achieved.

A plexiglass model of an above-knee amputation stump has been used to test the reproducibility of the instrument. This shape was measured 20 times in each of 3 different sized measuring tanks. Surprisingly the repeatability was not found to be related to the size of the tank except for measurements over the distal 3 cm of the shape. An example of the superimposed 20 measurements obtained with the 25 cm diameter tank is shown in Figure 4.

**Sample result**

Comparison of two cross-sectional area profiles of a 19 year old male above-knee amputee is shown in Figure 5. The curve labelled A was made prior to applying an elastic tensor bandage for a duration of one and one-half hours. The measurement taken after the bandage was removed is labelled B. Very little difference between the two curves is demonstrated.

**Discussion**

Several techniques have been used for body shape determination including measuring tapes and calipers (Girling et al. 1972, Pritham 1974, Staats 1974), contour tracers (Newman 1966, Zuniga et al. 1977), photogrammetry (Herron 1970, 1972), and water immersion (Dempster 1955, Drillis et al. 1964, Contini 1970).

Previous immersion methods of measuring the volume changes in extremities have relied on one of two principles. In its simplest form volume displacement consists of placing an extremity into a tank full of water and measuring the overflow (Dempster 1955). This system has two disadvantages:

1. It is difficult to immerse the limb to the same depth on each measurement.
2. Only one figure is obtained representing a total change in volume.

Naturally a situation such as a proximal constriction leading to a distal swelling would...
tend to produce a small change in total volume since one would tend to cancel the other.

An approach has been tried by other workers to remove this second deficiency (Contini et al. 1963). In this approach known quantities of water are added to the tank and the rise in water level is measured after each addition. That increase in water level is proportional to the volume of the particular section of the amputation stump that becomes immersed.

An alternative approach is to fit the tank with a syphon that is lowered by discrete intervals and the volume overflow is measured (Contini 1970). Both of these systems are very complex to operate and take a considerable amount of measurement time.

The use of the simple principle embodied in the design of this new instrument removes both of the major deficiencies of the previous systems.

The design of this new instrument eliminates the problem of marking the limb to facilitate comparison between measurements since the distal-most point of the limb automatically becomes the reference point. Some difficulties were encountered initially because of surface tension effect influencing the determination of the end of the stump. It was found desirable to incorporate a switch in the instrument by which means the operator signalled directly to the computer when the water surface was seen to detach from the skin.

It might be expected that geriatric patients may be apprehensive about being tested in such a complex instrument, however we have found this not to be a problem. The harness and supporting pads have proved to be adequate for holding the patients still. This firm support has provided the patients with a feeling of security which is reinforced by the operator's description of the testing process.

The effect of water immersion on limb shape due to hydrostatic pressure and buoyancy effects is unknown. However, it is assumed to be relatively constant for an individual. Similarly, alternative methods of measurement in air suffer from the unknown effect of gravity on dependent tissue.

Objections to immersing tissue that has not completely healed have been overcome by the use of self-adhesive surgical drape.

Summary

This paper has presented a description of a new system for measuring body shape by a water displacement technique. It is hoped that this development will be valuable to others interested in the measurement of shape and changes in shape.

REFERENCES


