*Spring 1972*

# Artificial Limbs

*A Review of Current Developments*

COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT

COMMITTEE ON PROSTHETIC-ORTHOTIC EDUCATION

**National Academy of Sciences**

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# TRANSITION

A. Bennett Wilson, Jr.

The National Academy of Sciences began publication of *Artificial Limbs* in 1954 because, at that time, there was available no periodical for the systematic dissemination of the results of research in limb prosthetics. Since that time 33 issues have been published and made available without charge to an average of 5,000 individuals concerned with the management of amputees.

Also, since the initiation of *Artificial Limbs*, the Veterans Administration Prosthetic and Sensory Aids Service has introduced the *Bulletin of Prosthetic Research*, and the American Orthotic and Prosthetic Association and the American Academy of Orthotists and Prosthetists publish the journal *Orthotics and Prosthetics* which is now devoted entirely to technical and professional topics.

Thus, in keeping with the philosophy that the National Academy of Sciences should not undertake programs that can be carried out by others, publication of *Artificial Limbs* will be discontinued with this issue. This decision will permit the Committee on Prosthetics Research and Development and the Committee on Prosthetic-Orthotic Education to devote the time and funds that would have gone into production of *Artificial Limbs* to the production of monographs and other publications that are not apt to be made available otherwise.

Information that would have appeared in *Artificial Limbs* will now be found in the *Bulletin of Prosthetics Research* and *Orthotics and Prosthetics*.

The reception given to *Artificial Limbs* through the years has been very rewarding to the staff, and even though it is with regret that we must advise discontinuance of its publication, we feel that the move is in the best interest of the Prosthetics and Orthotics Program.

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# Body Segment Parameters, Part II[1]

RENATO CONTINI[2]

THE performance of human (animal) activity requires the expenditure of energy. During the contraction of the muscles involved in this activity, chemical energy is converted first into mechanical energy, then into work and heat. Some of this chemical energy is required for maintenance of body functions. In movement, however, much of the mechanical energy is required to overcome friction and tissue displacement at the joints, gravity, inertial forces, air and water resistance—all of which oppose the action desired.

Biomechanics is the science that is concerned with such effects. In order to understand better the biomechanics of movement, it is necessary to know certain characteristics of the segments involved. Among these characteristics are the mass of the segments, their centers of mass, and their mass moments of inertia. The characteristics (body parameters) themselves are not readily obtained on living subjects.

It was the purpose of two studies conducted at the New York University School of Engineering and Science to obtain some of these body parameters. The first of these studies (*6*), completed in 1966, was conducted on normal, healthy American males in the age range of 20–40 years. The second study (*3*), completed in 1970, was conducted on a random selection of adults, young males and females 20–30 years of age, some females in the 40–50 age bracket, and a number of amputees and hemiplegics, male and female, in all age ranges.

A history, survey of measurement techniques, and data developed over the years was given in "Body Segment Parameters: A Survey of Measurement Techniques," which appeared in *Artificial Limbs*, Spring 1964 (*7*). Also, a condensation of four of the most important monographs in this field ("Center of Gravity of the Human Body" by W. Braune and O. Fischer; "Theoretical Fundamentals for a Mechanics of Living Bodies" by O. Fischer; "The Human Motor" by J. Amar; and "Space Requirements of the Seated Operator" by W. T. Dempster) has been prepared by Krogman and Johnston (*10*) under the sponsorship of the United States Air Force.

## METHODS

Most studies undertaken previously used cadavers, but in a few studies, including those at New York University, living subjects were used. Although some available measuring techniques for compiling the data are similar for live subjects and for cadavers, other techniques must obviously differ. In general, the techniques covered here are for living subjects; thus, all techniques used on dissected cadavers are not included. When living subjects are used, particularly the elderly and those suffering with some affliction or disability, any technique utilized must be at the convenience of the subject. Some subjects cannot comfortably assume the necessary postures during the measurement processes, while for some others the procedures are physically impossible. As a result, not all measurements can be taken on all subjects, but, because of the various tech-

[1] The investigations on which this article is based were supported principally by two research special projects grants—one from the Office of Vocational Rehabilitation and the other from the Social and Rehabilitation Service, Dept. of Health, Education, and Welfare.

[2] Prosthetic-Orthotic Education Program, UCLA, Los Angeles, Calif.

niques available, most of the desired data can be obtained.

The techniques are only briefly presented here because more adequate descriptions are available in other references.

### VOLUME DETERMINATION

The body and all of its segments are irregular solids. The volume of an irregular solid may be obtained or approximated in a number of ways: by mensuration, immersion, or photogrammetry. Only the first two were used in both studies.

#### *Mensuration*

A relatively good approximation of body-segment volume can be obtained by using circumferential measurements at certain selected stations on the segment and the linear dimensions between any two consecutive circumferential measurements. If all these measurements are known for the full length of the segment, then an approximate volume can be determined. Accuracy will increase with the increased number of such measurements. This technique assumes that any two successive cross sections of the member are parallel and essentially similar geometrically. In that event, the volume contained within the two cross sections may be expressed as:

$$V = \frac{h}{3}\left[B_1 + B_2 + (B_1B_2)^{1/2}\right] \quad \text{where,} \qquad [1]$$

$B_1$ and $B_2$ are the areas of the respective cross sections and $h$ is the linear distance between them.

It is obviously impossible to obtain cross-sectional areas on the body segments of living subjects. If it is assumed, however, that the cross sections of the limbs are elliptical, it is possible to establish a relationship between the cross-sectional area and the perimeter at any chosen level. For any segmental portion between two levels, the volume may now be expressed as:

$$V_s = \frac{K}{2}(P_1 + P_2)^2 h, \quad \text{where,} \qquad [2]$$

$P_1$ and $P_2$ are the circumferential dimensions at levels 1 and 2
$h$ is the distance between $P_1$ and $P_2$
$K$ is a constant for which the most reasonable value appears to be 0.0778

For a total limb divided into $n$ segments, each $h$ distance apart:

$$V_S = K(P_1 + P_2 + P_3, \ \ldots, P_n)^2 \cdot h(n - 1) \qquad [3]$$

The derivation of this equation is given in reference *3*.

#### *Immersion*

In this method, the segment whose volume is to be determined is immersed in water. Incremental volumes are taken of the segment whose total volume then is the sum of these increments. For these studies, four tanks were specially designed: an arm tank, a hand tank, a leg tank, and a foot tank. Each tank was constructed of Plexiglas, the first three cylindrical in cross section, and the last, rectangular.

The limb or body segment was completely immersed in the tank. Water was permitted to drain off in controlled increments, each representing a known change in cylinder height. Drained water was collected and measured. The difference in volume between that collected and that obtainable without the body segment in place (the actual volume of the tank for that increment) represents the volume of the body segment contained within the height increment. Whenever possible, these increments were 2.0 cm apart, but, if subjects with limited physical tolerance had minimal cross-sectional variation, the increments were increased to every 4.0 cm apart.

#### *Photogrammetry*

Two types of photogrammetric techniques are available—mono and stereo. In