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QUARTERLY REPORT NO. 3

STUDY OF THE HINGE POINTS OF THE HUMAN BODY

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## ABSTRACT

This report is essentially an inventory of the research program as it has developed to date. Equipment and general facilities are now at a stage which allows effective gathering of data along most lines of the projected study.

Work has advanced along three fronts: First, bones and articular surfaces of the principal extremity joints have been studied intensively to locate the path of the instantaneous axes of movement at each joint. Also extremity links interconnecting neighboring axes have been identified. Individual joint dissections have been studied from a mechanical standpoint, and a whole-body ligament preparation has been subjected to functional analysis.

Second, small samples of preserved (two specimens) and unpreserved (four specimens) cadavers have been systematically dismembered, and data on mass, volume, density, center of gravity, and moment of inertia have been derived on the various trunk and extremity segments. In addition, four preserved bodies have been sectioned transversely and, from the slices, data were derived on the mass, center of gravity, and percentage of bone, muscle, skin, and viscera of each section.

Third, studies on nude living subjects were developed on a small group of more or less inselected young male adults. So far five of these have been studied extensively, studies on a sixth are in process, and the data are being subjected to analysis. Extensive measurements including anthropometry, transverse sectional areas of the body, and extremity volumes have been made. These should allow comparisons with cadaver data and the assigning of reasonable estimates of segment mass, centers of gravity, and moments of inertia. In addition, the ranges of movement of the various extremity joints and the angulations of the pelvis for various postures have been measured. The geometry of the space envelope, which includes the whole range of possible hand and foot positions (for various angles of tilt), has been recorded relative to the seated subject. In addition, records of representative movements within the space envelope have been obtained. On the basis of the foregoing experience, study schedules have been revised. The collection of schedule-data upon a more extensive group of subjects, involving selected body types, has begun.

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THE GENERAL PROBLEM

Though several months' effort on the present investigation has seen certain changes in emphasis and methods not originally anticipated, the basic objectives remain the same. The research program is directed toward studying fundamental features of the body geometry relating especially to the major extremity joints in both living subjects and cadaveric preparations. In addition, the study is directed toward finding such data as the masses, centers of gravity, volumes, densities, and moments of inertia of the body segments from cadaver material. Extensive measurements on both living subjects and cadavers are to be made with a view to adapting data derived from cadavers to selected living subjects. Primary emphasis is directed to limb segments, and it is intended to develop information relating to four representative body types. As the work continues, practical problems relating to manikin design and to the applications of body mechanics to the pilot in his cockpit will be studied.

WORK TO DATE

The function of this report is to present a general inventory of progress to the present time.

Equipment and Facilities

Construction of general facilities for the main-line research is virtually complete as of this writing. A special room is fully equipped for the work with unpreserved cadaver material and another has probably 95 per

cent of the desired facilities for work with living subjects. Both work rooms have been used for several months in preliminary and exploratory studies as well as in more routine data gathering. Leads from the basic study, supplementary data, and later points of practical application will probably call for some further additions and changes, but the present concern is the use of the facilities now at hand.

### Work Schedules

Recently, preliminary work and the earlier data were checked as to general content and, in relation to the overall picture, most of the study schedules were revised to some extent so that they interrelated better. There are now 12 schedules relating to procedures on living subjects. These include anthropometric measurements, body and limb volumes, angles indicating the range of joint movement, and the localizing, relative to a standard seat, of hip and shoulder axes. The schedules deal also with the possible positions of the hand in space for various grip orientations and with the possible positions of the foot (at representative angles) relative to the seated posture (these studies pertain to lever and pedal positioning). One schedule related to actual movement data (velocity, acceleration, pattern, etc.,) of the limbs in the sagittal plane. Each schedule deals with a class of data to be derived from nude male study subjects. A study subject is expected to spend 20-25 hours as data for the schedules are gathered. Additional procedures which will relate to only a few selected subjects are planned to supplement several schedules.

Five basic schedules relate to the cadaver study, and these cover such items as anthropometry, segment mass, segment volume, segment oscillation time when swung as a pendulum, and the percentage of bone, muscle, and integument. Supplementary checks and measurements are planned in several of the procedures.

### Subjects

Since the month of May, some 15 unselected male student subjects have been somatotyped and, on most, one or more schedules of data have been obtained. The somatotype diagnoses have been determined from our photographs by Professor C. W. Dupertuis of Western Reserve University. Several of these subjects are now no longer available for further study, but most of them are. Five have contributed, and a sixth is contributing to nearly all the schedules, and every schedule-study has been followed on one or more of these men.

Recently, through a screening at the physical examination for entering students at the University of Michigan, 25-30 prospective subjects

have been selected from more than a thousand students. These subjects were those who were high in endomorphy, mesomorphy, or ectomorphy. They are now being further screened by the somatotyping procedure to provide highly selected subjects with a 6 or 7 rating in the high component. It is proposed to derive scheduled data from these men during the next several months.

#### Cadaver Material

Four preserved bodies have been sawed into transverse sections; data on section mass, on the location of section centers of gravity, and (in two of the subjects) on the percentage of integument, muscle, skeleton, and viscera were determined from these sections. Similar data on unpreserved bodies will not be derived until a later time, since special installations must be developed to protect personnel from potentially infected sawdust.

Two preserved and four unpreserved bodies have so far been subjected to scheduled procedures relating to limb and trunk segments. Anthropometric data and data on mass, segment center of gravity, volume, per cent muscle, bone, etc., and oscillation time of segments (for determination of moment of inertia) have been obtained. Each of the above procedures related to segments and units such as: the whole trunk and head, the separated head and neck, the thorax, the abdomino-pelvic complex, and the right and left shoulder masses. The right and left upper and lower limbs were first treated as whole units; then units consisting of middle and distal segments and units consisting of separate proximal, middle, and distal segments were measured. Thus, 24 body segments in all were measured for each subject and several parameters were involved for each segment.

#### Joint Study

Quite apart from the foregoing emphasis, intensive study has focussed on the articular surfaces of the bones that relate to the major joints of the upper and lower limbs. This study of cadaver material has brought to light a critical relationship to the "hinge point" problem, since it has shown that no major joint has fixed "hinge points." Rather the axis of joint rotation shifts momentarily with each phase of joint positioning. The instantaneous axes for rotation lie on an evolute curve of distinctive shape for each joint. Evolute curves have been derived from groups of cadaver extremities, and plots are at hand for glenoid fossa of scapula, humeral head, capitulum and trochlea of humerus, sigmoid fossa of ulna, proximal and distal articulations of radius, and the radial articulations of the navicular and the lunate bones. In the lower extremity, our plots of evolute curves relate to acetabulum, femoral head, femoral condyles, distal

tibial articulations, and the talus bone. The characteristic pattern of evolute curves, implying a changing radius of curvature of articular faces, correlates with a changing link distance between an axis at one joint and that of the next joint for each pattern of limb posture. The geometry of the functioning skeleton in movement is thus not that of a simple stick-figure mechanism. Experimental manikins with pin-centered joints accordingly are not quite realistic. The degree of departure will soon be determined in our studies. The application of our data to manikin design is a subject for subsequent study.

Separate dissections of various joints have been and are under study from a mechanical standpoint, and a whole skeleton-ligament preparation showing composite limb movements has been of value.

#### Subsequent Work

The program of study has reached a stage in which effort should be directed toward: (1) obtaining a greater amount of data - especially on living subjects of selected body types; (2) gathering more routine data on body segments from unpreserved cadavers; and (3) completing the study of articular surfaces of bones. These emphases are planned as the major effort for the months immediately ahead.

