ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

QUARTERLY REPORT NO. 2

STUDY OF THE HINGE POINTS OF THE HUMAN BODY

By
(Wilfrid Taylor)
W. T. DEMPSTER
Associate Professor of Anatomy

Project M996

WRIGHT AIR DEVELOPMENT CENTER, U. S. AIR FORCE
CONTRACT NO. AF 18 (600)-43, E. O. R695-70 PO-12j

June, 1952

ABSTRACT

The present report reflects a shaping-up stage in project development, in which basic equipment and constructions are almost complete, the principal methods have been tried, and leads begin to interrelate and converge upon the main problem.

Five main phases of the project are taken up in this report. These are:

1. The problem of sawing extremity segments apart to obtain mechanical data is discussed and a plan based on average mid-range postures of joints and instantaneous joint axes is developed.

2.a. The curvatures of the articular surfaces of the principal long bones of the upper and lower limb have been studied by end-on measurements. These permit the defining of radii of curvature and the localizing of axes of movement(hinge points), and they lead to a concept of the body as a system of mechanical links. Such links have been defined and the axes have been located relative to anthropometric landmarks.

b. A more refined treatment of the whole curvature profile of the articular surfaces shows that most joints do not have anatomically fixed axes. The axes change positions with each joint posture, and their changing positions fall on evolute curves. These curves, indicating successive instantaneous positions of joint axes, have been plotted and have been localized relative to the anatomical contour of the bones. Extremity links, accordingly, have lengths that vary with functional posture. Links may be considered in terms of maximum, minimum, and mean lengths.

3.a. Records have been made on 16-mm film of a stripped-down skeleton-ligament dissection showing the extreme range of joint movement. A frame-by frame analysis of the film to date shows both free (open-chain) and restrained (closed-chain) movements of the lower limb segments relative to the pelvis, which was fixed rigidly. This study defines the possible positions that the limb segments may occupy, the range of movement, and the type of joint rotation involved.

b. Techniques for a parallel study of restrained movements for seated living subjects have been developed. This study will define, relative to a reference point in the "fighter" cockpit, the range of possible positions of handles, levers, and pedals for various angles and sets.

4.a. Techniques have been developed for the study of the mass and center of gravity of sawed serial transverse sections of cadavers.

b. Two methods of determining cross-sectional areas of the body at any height are compared. One is an original direct planimetric measurement of areas on the living subject; the other is the Weinbach method of measuring standardized photographs of subjects.

5. Plans and schedules that have been adapted for the selection and study of living subjects are summarized.

Certain aspects of techniques and equipment are illustrated. Problems now receiving attention and projected for the immediate future are outlined. Principal items of recent equipment are mentioned.

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STUDY OF THE HINGE POINTS OF THE HUMAN BODY

THE GENERAL PROBLEM

The present study is directed toward obtaining information relating to certain mechanical features of the various body members which will permit broader functional applications than can be made now. The approaches will derive data on body geometry, on body masses, and on such mechanical factors as centers of gravity and moments of inertia of parts. Both cadavers and living subjects are to be studied along parallel lines insofar as this may be done; in addition, data obtainable only from cadavers are to be derived and referred to living subjects. It is planned to develop information relative to four representative body types. Primary emphasis is directed toward the upper and lower extremities. As the work unfolds, certain practical problems relative to the body mechanics and movements of airplane pilots will receive attention.

THE PREVIOUS REPORT

The first quarterly report, in a section "Work to Date," dealt with two problems: (1) a discussion of the "extremity segment" as naively understood and the difficulties in defining it precisely for quantitative scientific purposes, and (2) a study of the principal convex articular surfaces of the upper and lower limbs. End-on measurements of the convexity of joint surfaces were made and radii of curvature and "interpivotal distances" were determined. Axes of movement were located relative to anthropometric landmarks. In addition, the report dealt with "Work Begun and in Progress" and "Work in Prospect." All items (p. 8-9) under "Work Begun and in

Progress" have continued except A-2 (on ligaments at joints), which may be abandoned. Items 2 and 3 (p. 9) of "Work in Prospect" have since received attention and are dealt with in this report.

WORK TO DATE

Five aspects of the investigation as indicated in the subheads below have been selected for comment in this section of the report.

Extremity Segments

Earlier workers on extremity segments (Harless, 1860; and Braune and Fischer, 1890) have simply sawed across the joints of the upper and lower extremity in the recumbent cadaver to separate the segments for study. One may, however, question whether mechanical data on segments separated in this way have maximum value for all functional analyses of movement and posture. The discussion on extremity segments in the previous report and work below on instantaneous axes of joint movement bring up theoretical objections to separations across straightened joints. Actually, segments will differ in mass to some degree according to the extent of straightening or bending at the joint. Mass differences are, of course, small for similar degrees of bending, but in some joints, at least, these should be of some magnitude between full flexion and full extension. Some intermediate position of bending for the joints bordering a segment should permit the defining of a plane for a saw cut which should give the best possible working data on segment masses and centers of gravity.

On the basis of some tests upon cadaver limbs, a plan for separation has been devised. This involves (1) bending each joint to the mid-position of its range—the hip thus is to be abducted, flexed, and laterally rotated to the proper position, the knee is flexed to mid-position, and so on for other joints; (2) locating the instantaneous axis for movement at this position, and (3) sawing across the axis and joint in such a way as to bisect the angle of bending. Studies on segments, currently under way, utilize this method for obtaining approximately mean values.

Links and Instantaneous Axes of Movement

A continuation of work on the articular surfaces of the principal upper and lower extremity joints has led to a recognition of the "interpivotal distances" as the functional equivalent of the "links" dealt with in the kinematics of the engineer. Strictly speaking, links are viewed as a two-dimensional system in which the articulating members overlap and are joined by pins which act as axes of rotation. Furthermore, transversely acting forces, as in lever mechanisms, are regarded as irrelevant. In contrast, body joints rarely overlap and none have pin-centered axes; the adjacent articulating surfaces of a joint are held firmly in contact by the dead weight of supported masses and by muscles and ligaments, so that one member moves about a center of rotation in the adjacent member by a sliding action at the contact points. Thus, the tibia rotates about an axis in the condylar region of the femur; similarly, it rotates about an axis beyond its lower extremity in the talus bone. In contrast, the femur rotates, relative to the pelvis and to the tibia, about axes traversing the bone itself. To apply the concept "link" to such a system involving an alignment of three bones would definitely strain the term. Nevertheless, the convenience of the concept of a mechanical axis would seem to warrant use of the term "link" as a functional equivalent of the link as used in engineering. In view of differences, however, it may be well in general, to designate body links specifically as thigh link, arm link, forearm link, and so on, and to define them relative to their special context in body functioning.

The link as considered in this work will be understood as the central straight line or core-line that extends longitudinally through a body segment and terminates at both ends in transverse or oblique axes (hinge points) about which the adjacent members rotate. The links as visualized here are the members which may be diagrammed on paper or represented in wire models as the units of a stick figure. At approximate centers of gravity, the links may be loaded with masses corresponding to those of the segments. Such loadings may be either on the line or eccentric. What is wanted is a functional simplification that may be visualized as the essential mechanical axis of the part. It will be convenient to treat links according to context. Thus, instead of 25 separate vertebral links, it may be desirable to group a chain of links into a unit that might be termed cervical link, lumbar link, and so on. Furthermore, one may think of a hand link alone or, if the purpose demands, he may think of further subdivisions involving finger segment links. It will be convenient to consider such end members or cantilever systems as the free hand or foot as links even though the distal end has no hinge. Such free end-links probably can be defined as lines extending from the hinge point to the center of gravity of the end member.

The body links, when known quantitatively, and, where possible, related to surface landmarks, should have value in extending the utility of conventional anthropometry. In the study of upper and lower extremities from twenty cadavers (cf. first quarterly report), end-on measurements of the curvature of articular surfaces gave values for radius of curvature and these when added to or subtracted from bone lengths defined lengths of

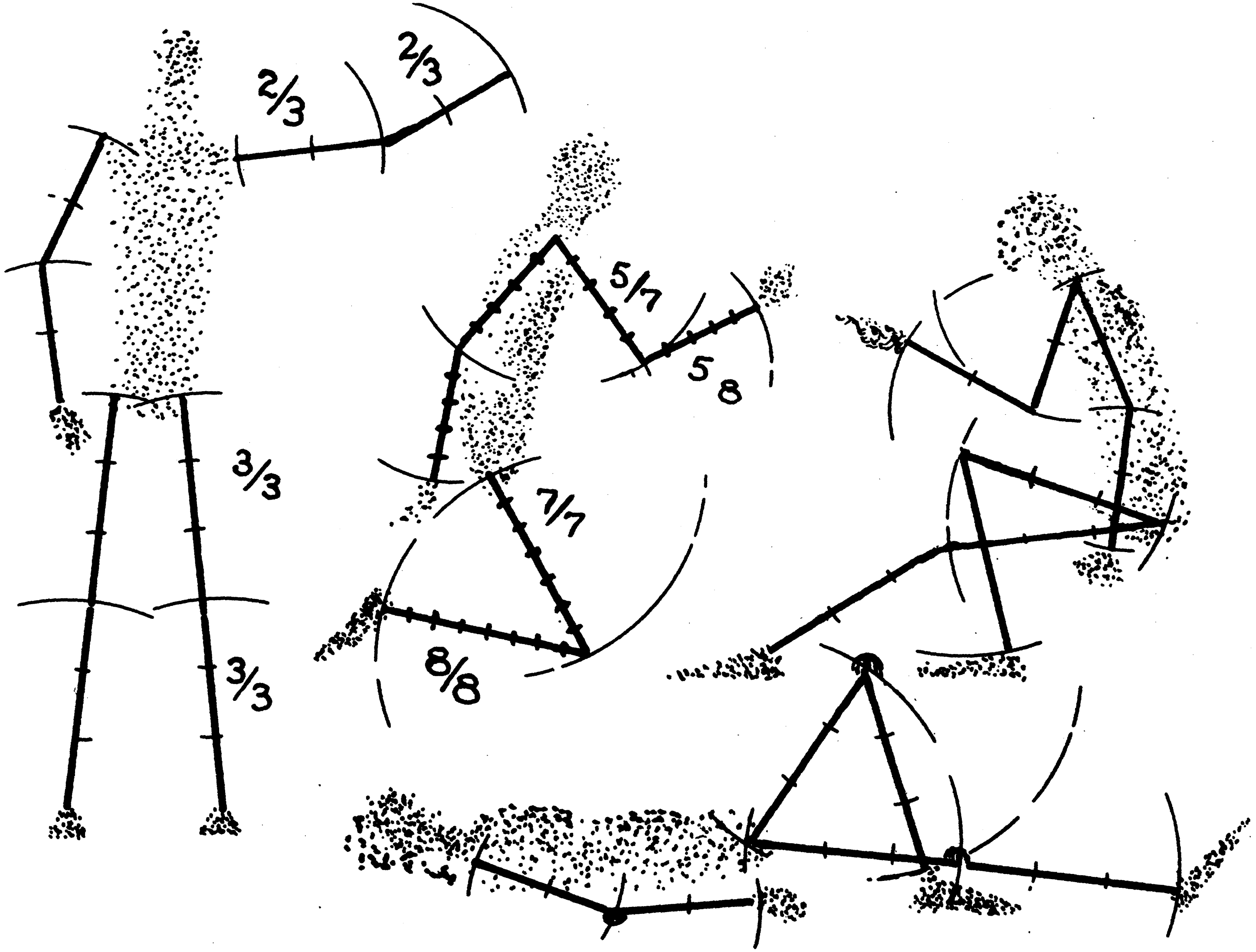

Fig. 1 The stick figures illustrated represent functional postures. Upper and lower limb links have been laid out with a compass using proportions based on average link dimensions derived from end-on measurements of the radius of curvature of articular surfaces.

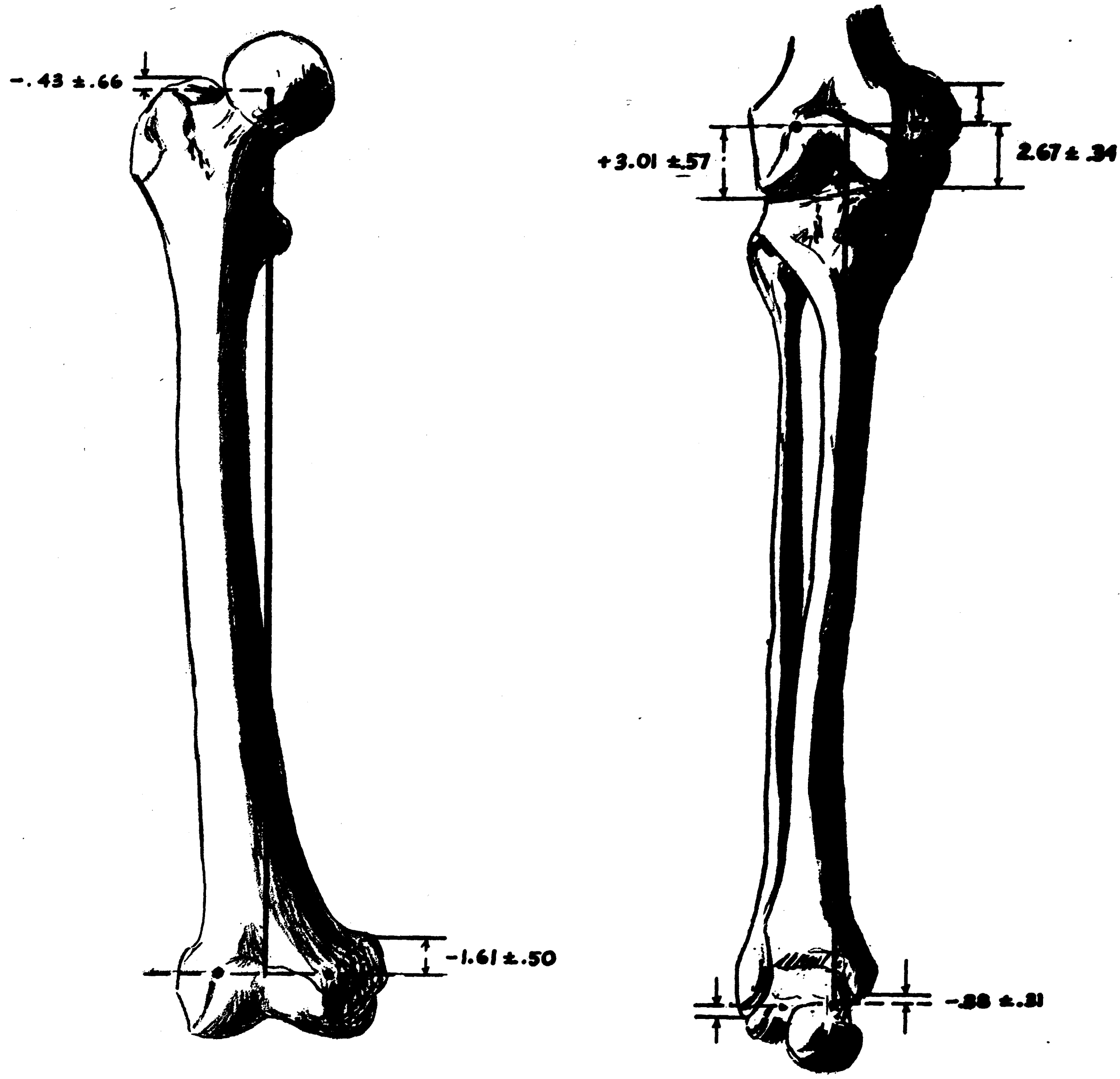

Fig. 2 Link relations in the femur and leg bones are based on end-on measurements of radius of curvature of articular surfaces. Centers of rotation are shown by dots. The locations of axes of rotation relative to anthropometric landmarks are indicated by measurements of the span intervening. Link dimensions are shown by the heavy vertical lines.

extremity links (Fig. 2). The thigh and leg links in our data averaged 408 ± 20 mm and 405 ± 20 mm respectively—practically the same. The arm link was 5/7 and the forearm link was 5/8 of the average of the thigh and leg links grouped together. Accordingly, it becomes possible, as in Fig. 1, to lay out these dimensions with a compass on a plane surface to represent a variety of body postures. This technique should have value in designing effective work accommodations for individuals who must operate from static standing or seated work positions. The possibility of using three-dimensional stick figures instead of compass drawings is obvious. When these ratios are translated in terms of the dimensions of the smallest, largest, and average personnel that may be involved in the design of work spaces, the engineer will have valuable working data. Various degrees of approximation are feasible; for instance, the combined average link-length of the arm and forearm, which comes to 2/3 of the leg or thigh value, may supplement the more exact 5/7 (arm) and 5/8 (forearm) ratios mentioned above. In the figure, the link systems of the trunk may be at present only roughly identified and the stippled areas suggest current ignorance.

The measurements of radius of curvature of the major extremity bones, mentioned above and in the previous report, have been end-on measurements. More recent work has led to refinements. Work appears to suggest that no extremity joints have fixed axes of movement; rather, there are instantaneous axes which vary in location with each postural angle of a joint. Even the apparently spherical head of the femur (and the acetabular surface) has a region of varying axis position that occupies a zone several mm across. An analysis of six femoral heads, eight acetabula, six femoral condyles (both medial and lateral), and six talus bones has been completed on selected bones from the twenty series studied earlier. The articular surfaces were selected as the most representative of the twenty cadaver series; they included two small, two large, and two medium-sized specimens for each type of bone. Upper-extremity joint surfaces are at present receiving attention.

The technique for the more refined study is as follows: Plaster (negative) moulds were prepared from the articular faces of the cartilage-covered bones and from these moulds two or more positive casts were made (Fig. 3). The positive casts were then sawed along planes which were determined by rolling the cast against a flat surface that had been chalked. The direction of rolling corresponded to functional movements and the chalk line transferred to the cast defined a line of contact normal to the surface—a great circle—that could be followed with a saw cut. Depressed surfaces such as the minimum diameter of the trochlea (of humerus) or the talus bone were sectioned along a plane through the greatest depression. After the cut surfaces were sanded plane and hardened in thin shellac, the outlines of the sectioned joint surfaces were traced on translucent plastic. Then projected tracings were made of the outlines. Plaster casts, rather than actual joints were sectioned so that (1) specimens could be saved for reference, (2) outlines of saw cuts on duplicate casts could be checked, and (3) spheroidal joint surfaces could be sectioned in different directions using a separate cast for each.

The contour of a cut surface, as represented in enlarged form, was divided by a compass into fifteen or more chords and perpendicular lines (i.e., normals to points on the articular surface) were dropped from them.

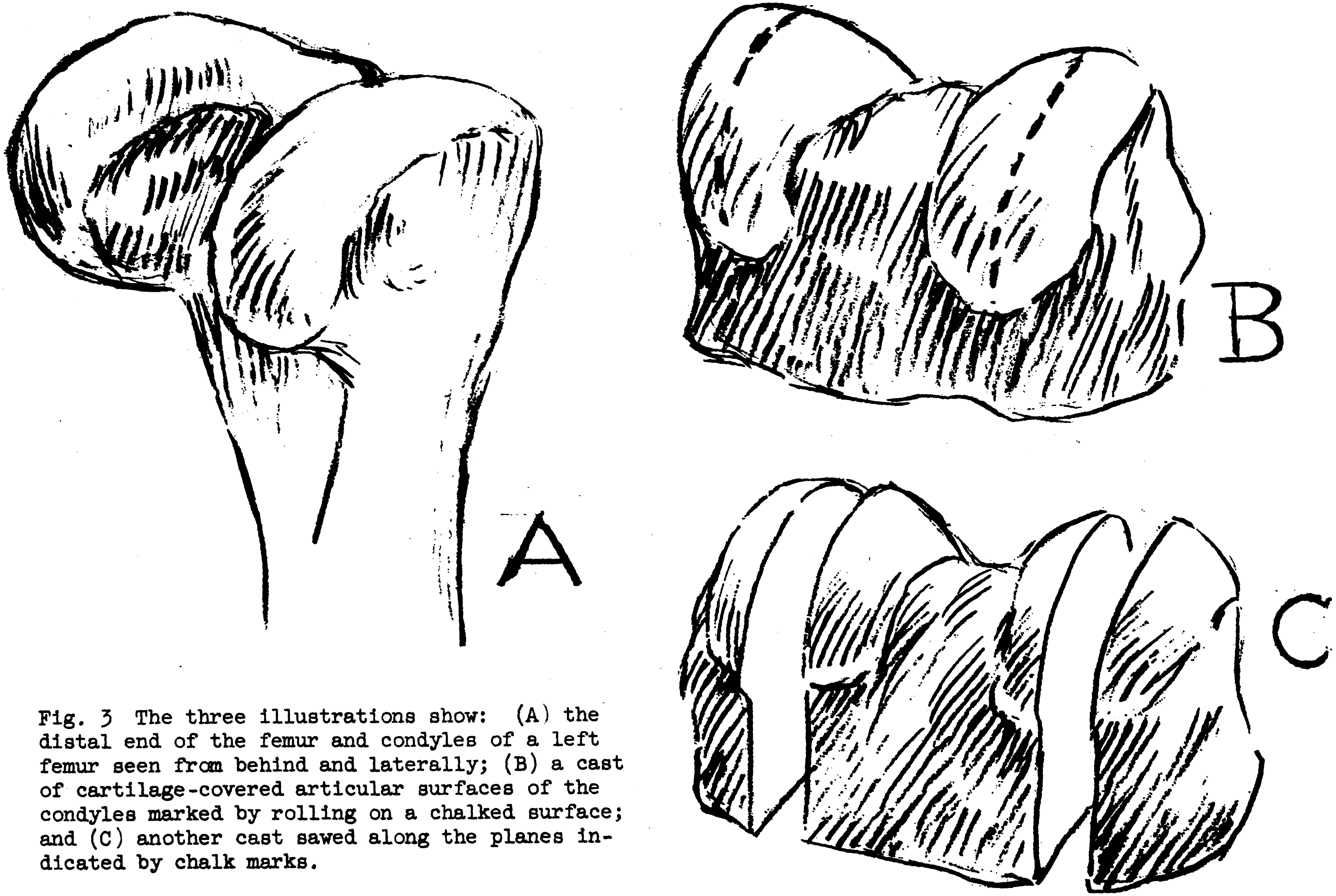

Fig. 3 The three illustrations show: (A) the distal end of the femur and condyles of a left femur seen from behind and laterally; (B) a cast of cartilage-covered articular surfaces of the condyles marked by rolling on a chalked surface; and (C) another cast sawed along the planes indicated by chalk marks.

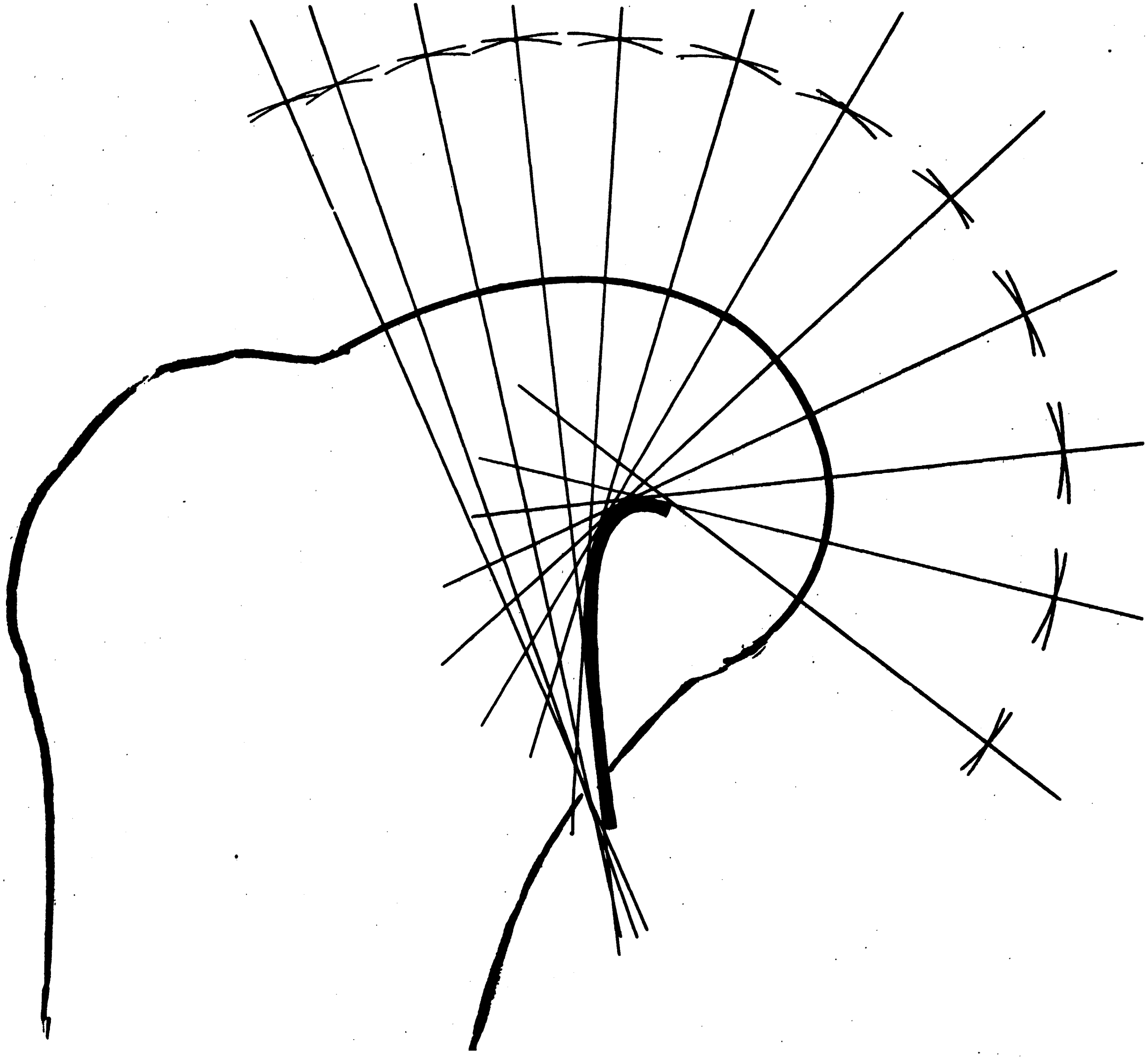

Fig. 4 A tracing of a section through the lateral femoral condyle. Perpendiculars to the aritcular surface have been laid out with a compass. Tangent to the perpendiculars is the evolute curve (heavy lines), which indicates the location of instantaneous axes of knee bending.

These normals, corresponding either to a whole articular contour or to a section of a contour, formed a pattern (Fig. 4) of successively overlapping lines. With a French curve a line known as an "evolute" could be drawn tangent to each successive line. Toward one end of an evolute curve, tangent lines were short; at the other they were long. These tangent lines represent radii of curvature for various parts of the articular contour and the points of contact with the evolute curve represent instantaneous centers or axes about which adjacent bones rotate. Bones rotate about these centers because the

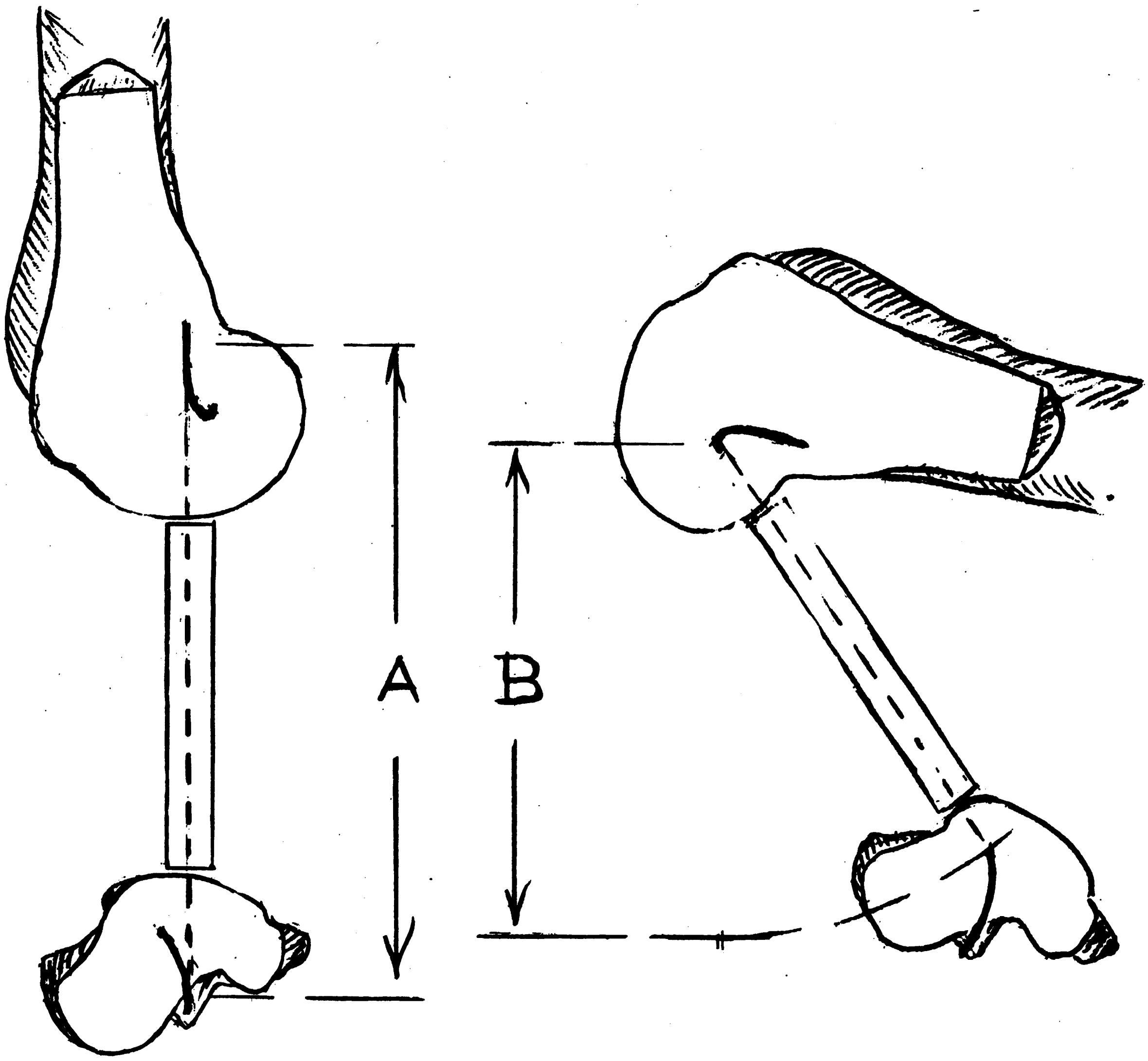

Fig. 5 The evolutes of the medial femoral condyle and of the medial ridge of the talus bone are shown at the left as in the standing limb and at the right as in a squatting posture. Leg bones are suggested by the short prism. Links that interconnect points on the upper and lower evolutes are shown to be longer for one posture (A) than for the other (B).

forces (muscles, etc.) which maintain contact between adjacent articular surfaces necessarily assure that the surface contacts are normal.

One evolute, as that illustrated for the knee (Fig. 4), means one continuous articular contour; two, three, or four mean that the articular contour is formed of subcontours each with its own system of curvature. Each joint has its own characteristic evolute pattern, and right and left show as mirror images. The femoral condyles (although both medial and lateral are distinctive) show single spiral-type evolutes, as does the medial talic ridge. The lateral talic ridge and the hip joint show composite star patterns of three to four evolutes. The evolutes of the lower limb vary in length from several mm to 2-3 cm.

Pins carefully placed and driven into stripped-down cadaver joint preparations form centers of rotation for only a limited degree of bending. The locus of the instantaneous center varies from moment to moment. Careful checks on living subjects (and fluoroscope checks, as well) show changing positions for the rotational axes.

If centers of rotation and radii of curvature change with posture, link lengths do also (Fig. 5). The changes, however, are systematic. Further study of dimensions and postures, including study of living subjects, will provide data for evaluations of the functional importance of these findings. Links based on average evolute position should provide better working data than the links mentioned above based on end-on measurements.

Extent of Joint Movement

A threefold approach to the joint movement problem has been developed: (1) literature review, (2) the study of a bone-ligament preparation, and (3) a study of joint movement in living subjects. Though the study is still under way, certain main outlines have become apparent. Aspects of our approaches will be outlined here.

A preserved cadaver has been stripped down to the various trunk and major extremity joints, and these in turn were carefully dissected to the essential supporting ligaments. This gave a preparation in which each joint showed an articulating mechanism that permitted movements like those in life. The range of movement approximated natural movement, but the extent was suspect, since ligaments had been exposed to embalming solution. More important, the type of joint movement (i.e., the degrees of freedom) could be demonstrated at all joints except those not dissected in the head and in parts distal to the wrist and ankle.

The pelvis was rigidly bolted between metal plates and the whole mass was made rigid by filling in with plaster of Paris. The pelvis was then fitted upright to a supporting frame. In the fixing of the pelvis, the latter was oriented so that the right and left anterior superior spines and the pubic symphysis fell on a vertical side-to-side plane. Any part could now be moved on its joint system so that movements relative to the pelvis could be demonstrated. With this preparation, all normal body movements could be approximated in a way not remotely possible in the articulated skeletons of the osteologist.

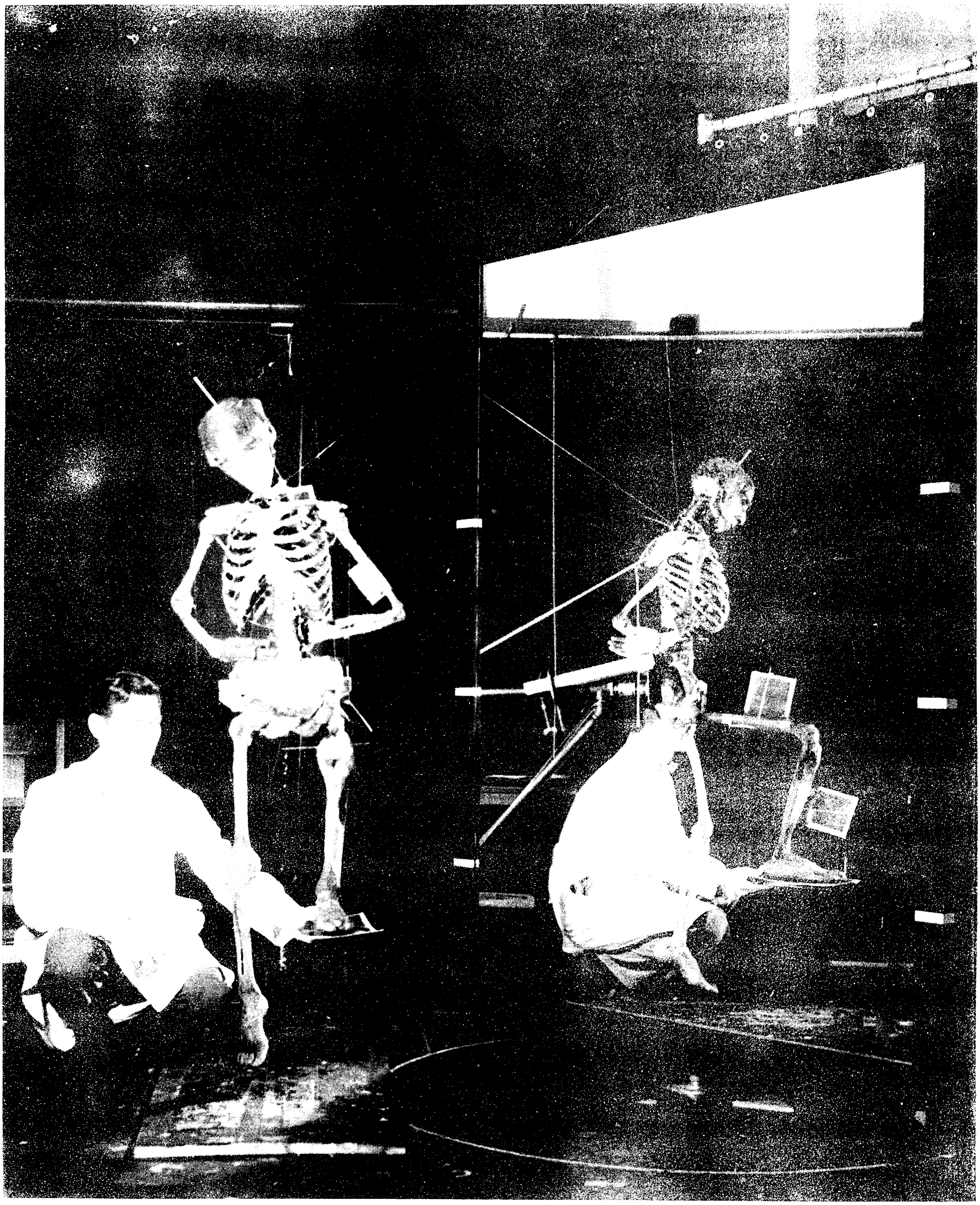

Fig. 1 An over-all view of a ligament-bone dissection that has been studied. The side view is shown in the 45° mirror. The left lower limb is being moved relative to the rigidly fixed pelvis.

The preparation was oriented frontally for photography and a 45° mirror showed a side view as well (Fig. 6). Various pins and two-dimensional fins were attached to the bones for accurate orientation. Finally, frame-by-frame exposures on 16-mm film were made showing the possible positions of bones and joints as these were systematically moved by an assistant. The photographic record was projected a frame at a time, and successive pencil tracings were superimposed to produce a record of movement range. A composite of the tracings then represented a successive series of bone (or link) positions and gave a comprehensive picture of the activity at joints. The operator who moved the joints of an extremity through their range of movement always held the moving part in positions where ligaments began to bind and limit movement. Thus, the composite pictures represented the extreme range of possible movement.

Various patterns of movement emphasizing one joint or another were developed for both upper and lower limbs. So far, however, only the photo records of lower limb movement have been analyzed graphically. Two patterns are illustrated in Fig. 7 and Fig. 8. In Fig. 7, free movements of the hip are shown in front and side view. On the occasion of this record, the knee was clamped in a straight position and the foot was nailed at 90° to the tibia so that the two lower segments of the limb moved rigidly with the femur. Thus, the figures demonstrate the extreme movements of the lower limb at the hip joint alone relative to the rigidly fixed pelvis.

The femoral link, together with the leg link, describes a cone-like figure (joint sinus) that opens forward and laterally. The sinus represents the extreme range of possible hip movement at positions where the ligaments at the hip begin to bind. Within the sinus, hip movements are free and the femur may radiate in any direction away from the acetabulum. Ligaments at the hip, however, still limit rotation more or less about the longitudinal axis of the link so that the foot, as fixed in the preparation, may toe in or out only within a prescribed range. The figures illustrates the location of the knee and ankle; still other data show various possible foot positions.

Our data show, in addition, the type of sinus developed by the foot relative to the pelvis when the knee is fixed at 90° or at other angles. Still other records show the effects of ankle flexion and extension. These types of movement are classed as free or open-chain movements. In such movements, the distal parts move freely in space within the range defined by ligaments and only one end of the chain of extremity links is fixed in space—the hip joint.

A second class of movements, probably more important for practical analyses, where subjects exert forces upon objects in their environment, are the restrained or closed-chain movements (Fig. 8). Here, the foot moves in

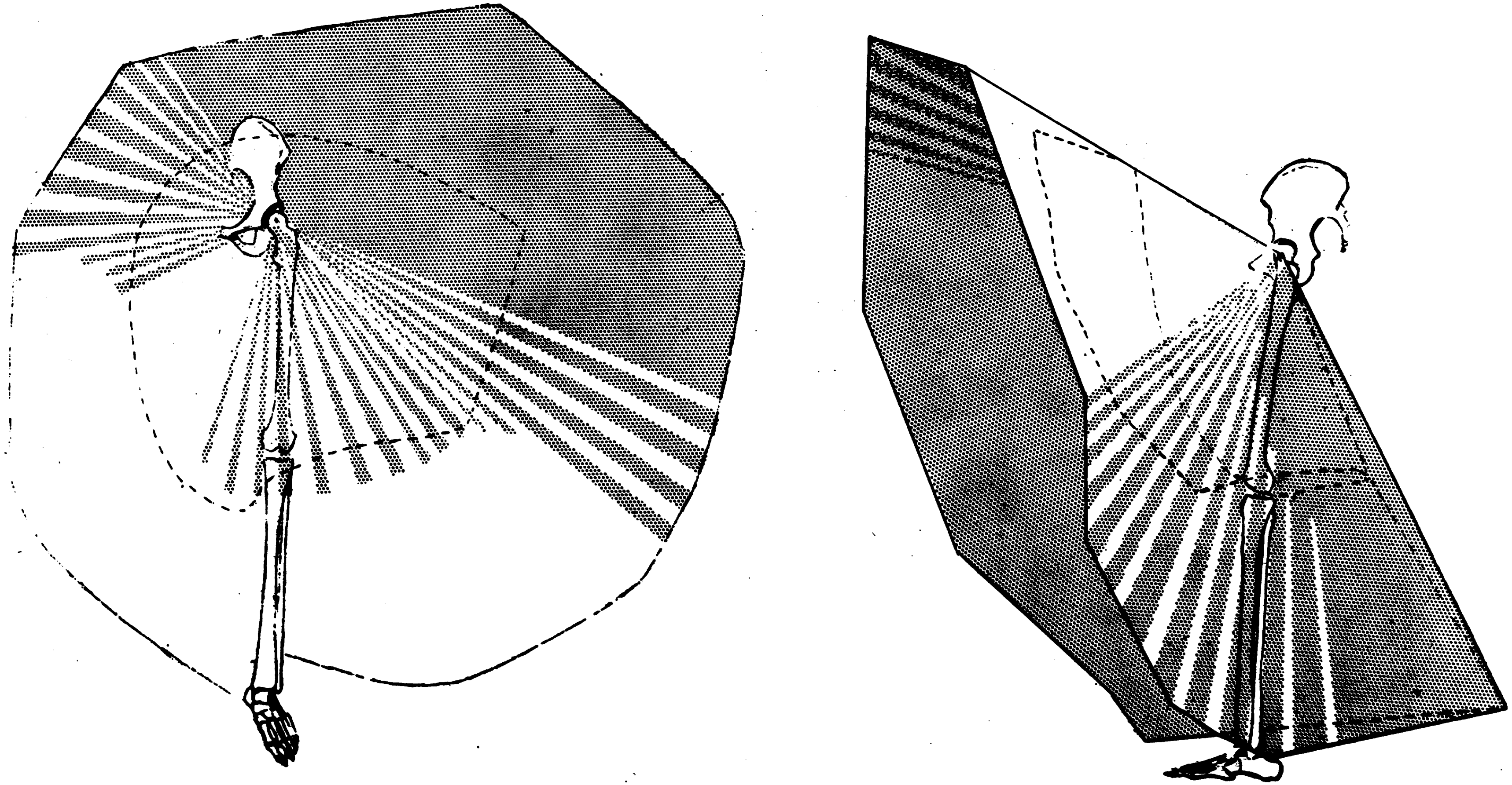

Fig. 7 The extreme range of free movements of the hip joint of a skeleton is illustrated for the straight limb. The joint sinus representing the extreme range of thigh and leg links is shown in front and side views.

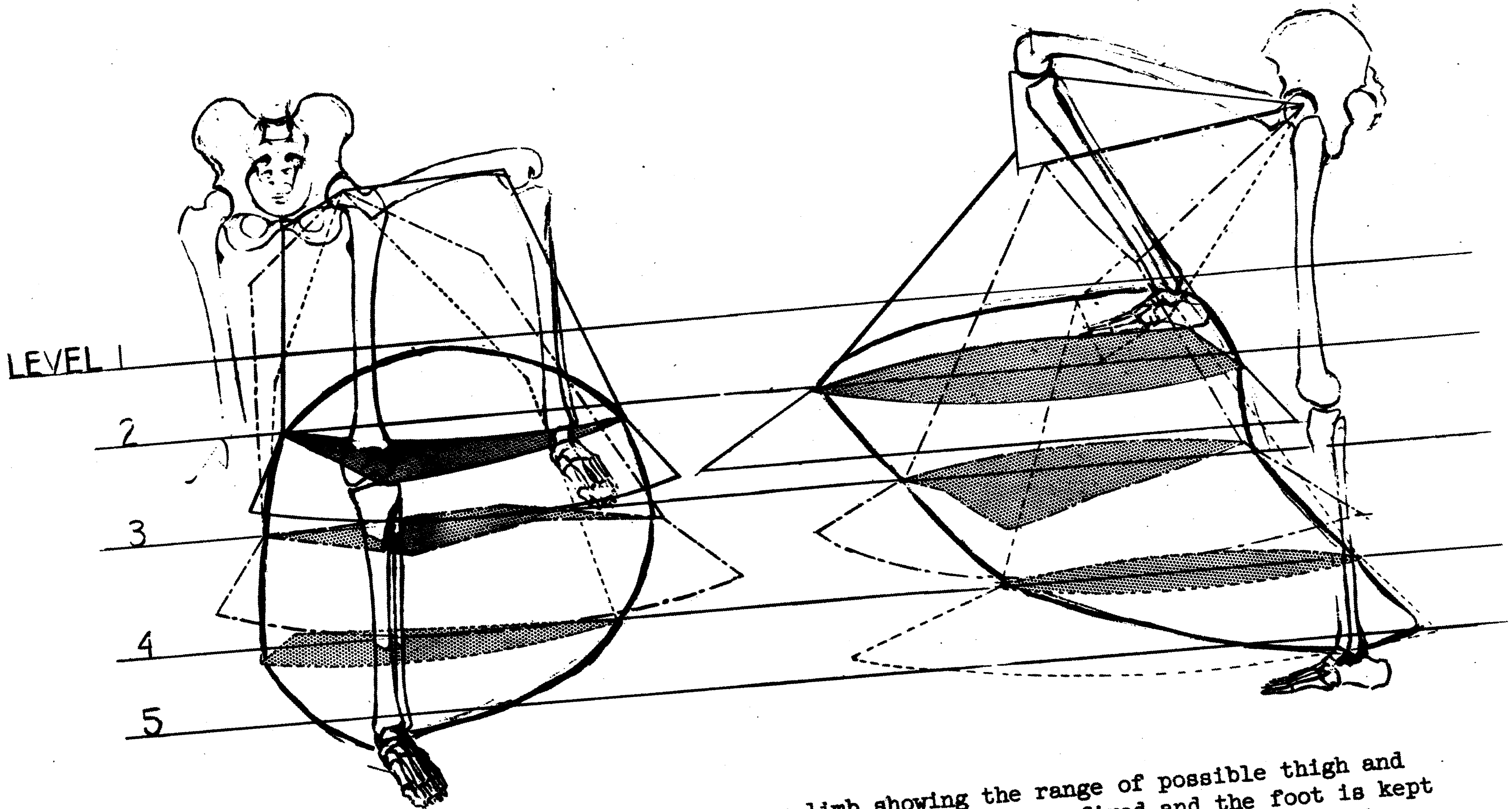

Fig. 8 This is a composite figure of the lower limb showing the range of possible thigh and leg positions for a restrained type of movement in which the hip is fixed and the foot is kept horizontal and directed forward. Stippled areas represent horizontal levels over which the foot may move. The heavy outline represents the space envelope that encloses the potential locations of the ankle joint.

continuous contact with a supporting surface and the toes in this instance are always directed forward. The joints between the foot and pelvis must adjust concurrently for any position of the foot upon the supporting surface. In this pattern of movement, the foot may scrub around on the supporting surface but this is possible only within a range prescribed by ligaments at the three joints. In one movement, the limiting factor may be the knee; in another it may be the ankle or hip. The extreme range of restrained movements was recorded for several levels of height, and Fig. 8 shows these levels as seen in perspective (stipple). The whole sphere or envelope of possible foot positions (under conditions of toes forward and footsole horizontal) describes a distinctive space pattern as is illustrated in heavy outlines. Other fixed angular positions of the footsole relative to the various horizons due to ankle bending (or toe-in or toe-out positions) would determine both a differently shaped and a differently positioned space pattern relative to the hip and pelvis locus.

All the skeletal limb movements were in relation to a pelvis fixed in a standard position. If the pelvis had been tilted to some other angle, the whole sinus or envelope pattern would always retain the same relation to the pelvis. Different positions of the bones in space were manually held by an operator while photographs were made; in each instance the position held was limited by the binding of ligaments. Embalming must be presumed to be a potential altering factor affecting the properties of ligaments. Accordingly, the range of movements shown in the photo record may not have corresponded exactly with the range before death. In contrast, in the living subject, entirely normal movements may be allowed by ligamentous restraints but the pelvis cannot be anchored as a rigid region of reference as accurately. This, however, was approximated in these studies in an indirect way. A metal frame was fitted over the upper pelvic region of our subjects and a reference plate was fitted over the two anterior superior spines and the pubic symphysis (Fig. 9). This plate supported a metal guide that was adjusted to the vertical position for the symmetrical natural standing posture of the subject. As long as the guide had the exact same orientation in space, the pelvis was similarly unchanged in its spatial relations. If the subject voluntarily held the guide in a fixed orientation, the effect would be the same as if the pelvis were rigidly fixed by external restraints as in the skeleton preparation. The pelvic guide system was used in studies of restrained lower extremity movements for subjects in both the standing and seated postures. In standing postures, the sacrum was placed against a vertical support and the skin over the pelvic region was taped to the support. The tape served as a reminder to the subject when the pelvis tended to move awry. The pelvic guide indicated any deviation and the subject voluntarily corrected his position as required during movements involving the foot and leg. In the seated position (Fig. 9) the tilt of the pelvis was indicated by an equivalent tilt of the pelvic guide. The pelvic region was taped to the seat and the guide was used to indicate and correct deviations from the initial position as

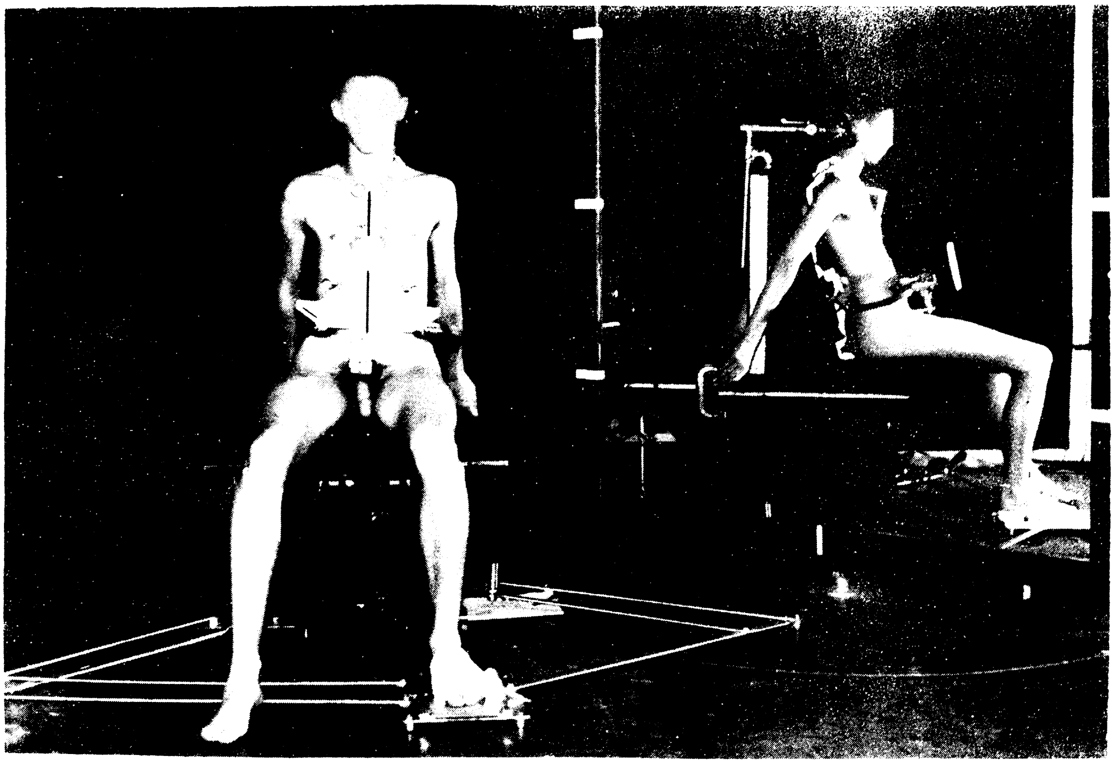

Fig. 9 The general set-up for study of movements of the lower limb relative to the "fighter" cockpit. The link system to the left of the foot keeps the foot and base plate directed forward for all foot movements at floor level and the pantograph to the right makes a record of movements. Attached to the pelvis and sternal region are supports for fins and guide lines which indicate the degree of pelvic and chest tilt.

the lower limb was moved. The figure also shows a guide placed over the sternum.

A footplate and a link mechanism (shown in the figure) forms a support for the foot and allows it to slide about over the floor. But the link mechanism (to the left of the subject's foot) keeps the heel-toe line constantly directed forward. At the right of the foot a pantograph attached to the footplate traces a record of foot movements. An operator slides the footplate and foot over the floor until the limit of movement is reached. Meanwhile the pantograph traces a record of foot positions. Throughout, the pelvic guide was kept at a constant orientation. Limitations of foot movement were caused by the restraints at the hip, ankle, or knee and the subject indicated which joint formed the limiting factor in restricting movement for various positions of the range. One or more blocks of standard thickness were piled on the footplate below the footsole position to provide successively higher foot level horizons. For each foot level, a pantograph record was made until a height was reached at which there could be no foot movement without tilting the pelvis out of alignment.

This technique, like the skeleton procedures, provided graphical data on the space envelope of possible foot positions for the fixed pelvis. Wedge-shaped blocks (30°, 45°, 60°, 75°) placed at any foot horizon can support the foot in new relations relative to the hip. With these, differently shaped space envelopes, differently oriented relative to the pelvis, are produced. A study of such patterns should define the range of effective foot positions relative to the pelvis and relative to reference points of a pilot's cockpit. Further analyses should give information contributing to the placement of pedal positions relative to the cockpit.

Distribution of Body Bulk

The following paragraphs deal with the development of techniques which will supply data on the mass or the volume of the body in a sequence of transverse levels relative to body height, one method is the Weinbach technique for calculating sectional areas and from these computing volumes. This method can be applied to both living individuals and cadavers. A second method, relating to mass, is the weighing of saw-cut sections of cadavers. The third method involves direct measurement of areas of the living body at various transverse levels; from these areas, volumes may be computed or determined graphically with a planimeter.

Initial determinations were made using Weinbach's technique of measuring body diameters from photographs, usually standard somatotype photographs that had been enlarged until the body height was approximately 8 inches. These body measurements were taken in mm and, assuming that a body cross section is an ellipse, the area was computed by formula for each horizontal position measured. The first measurements were made at 5 mm intervals on the photographs, but plots of the area data showed that a series of twenty critically selected body levels would give as accurate a contour area curve as the forty or so measurements made at 5 mm intervals. These twenty body levels were all defined relative to surface landmarks and the heights of these were measured so that levels were fixed rather than floating. The areas obtained from body diameters were then plotted on standard mm paper, and the over-all area of the curve was determined by a planimetric measurement which represented total body volume. Contour area curves were plotted for both the living subject and the cadaver. Fig. 10 shows a plot of the area contour for individuals representing extreme somatotypes.

There are certain intrinsic difficulties in the Weinbach assumption that body cross sections are represented by ellipses. Due to parallax in the lateral photograph, the contour line of the body profile was not a true mid-line profile. The shoulder, pectoral region, scapular region, and buttock (all several inches closer to the camera) contributed as much to the profile as the nose and lower face, the neck, and the lower belly, which presented mid-line contours.

Only preserved cadavers have so far been frozen and sawed into transverse sections and studied. Two males and one female cadaver have been photographed from the front, side, and back and then sawed into approximately 30-mm sections. Each individual section was photographed and half-size prints of representative sections were made. Section areas were determined by a planimeter. Areas determined from the over-all cadaver photographs following Weinbach's technique and those from pictures of cross sections were compared. The closest agreement came in areas where the body was most nearly an ellipse, and conversely, discrepancies appeared

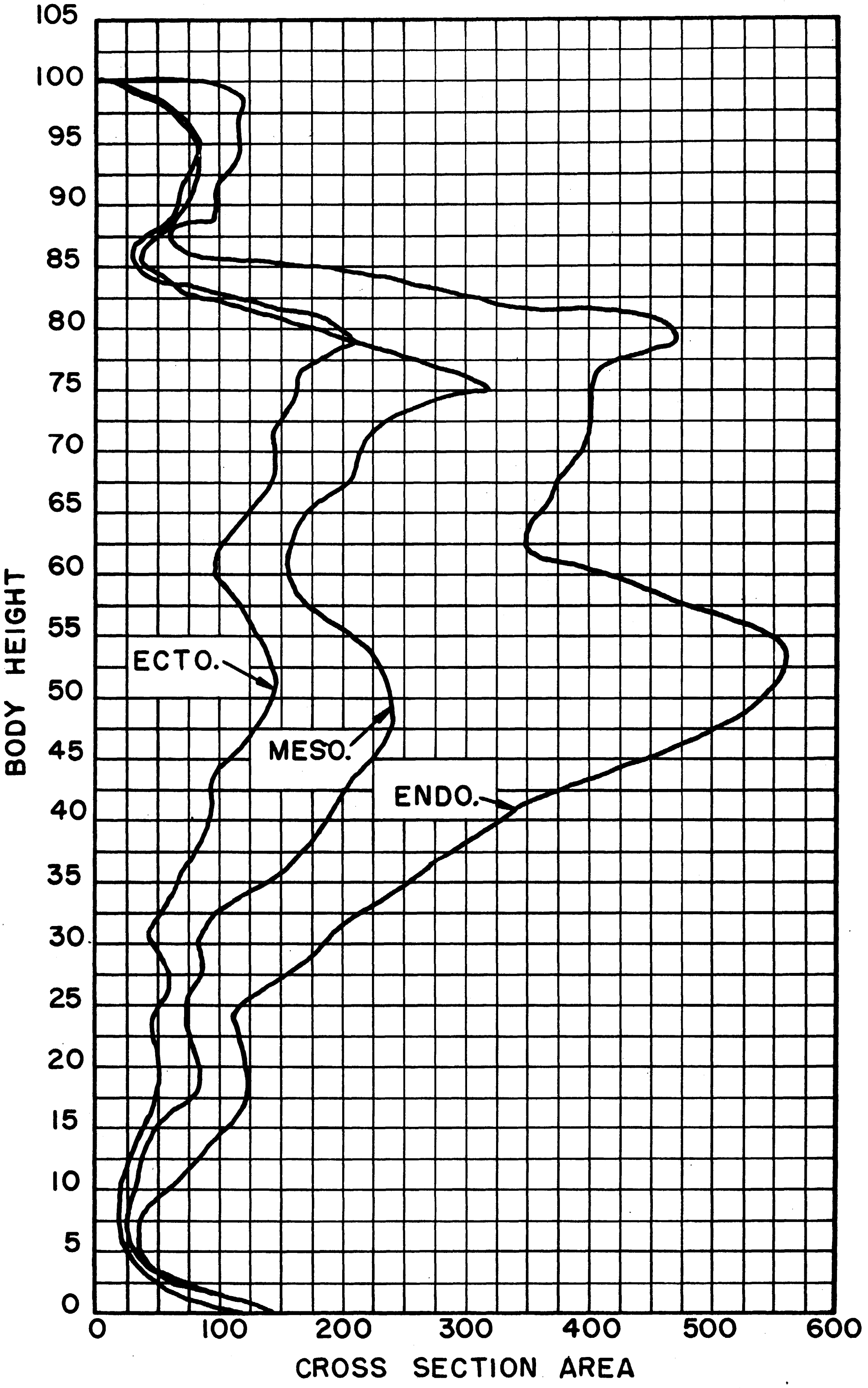

Fig. 10 Plots of area-to-height records, from data by the Weinbach method, are shown for three extreme body types. The area under each curve represents body volume (upper limbs are omitted) and the contour shows distinctive aspects of bulk distribution. The figures are all adjusted to the same body height.

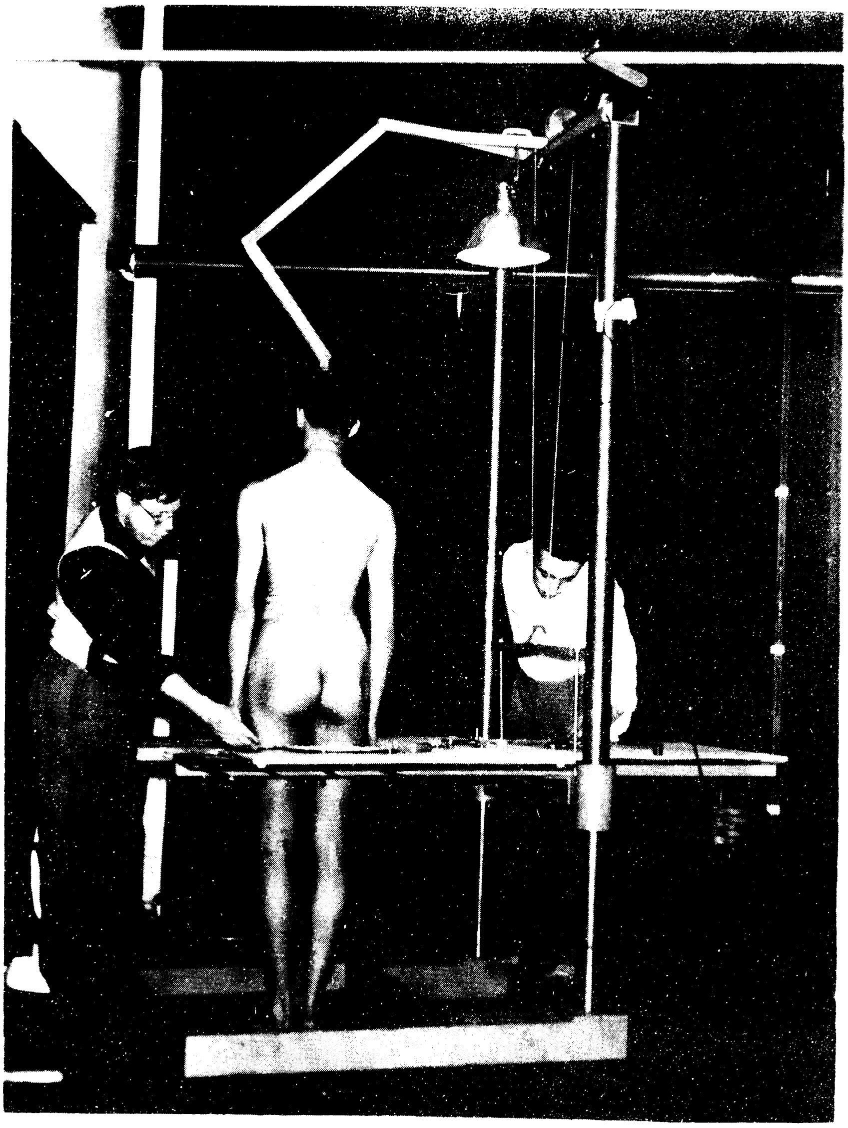

Fig. 11 The body area measuring apparatus is shown with the subject in place. The operator at the left traces the transverse body contour at the level of the table height with the tip of the curved planimeter arm and the man at the right records the planimeter readings. The crank and rachet at the top right of the frame adjust the height of the table relative to the body for each new measurement.

where the contour of body sections was less regular, e.g., the upper trunk. For accurate records of area from photographs in regions where the body section is not truly elliptical, conversion factors may be necessary

Standard anthropometric measurements were taken at the same body landmarks used in the photographic studies. These measurements were circumferences, diameters (both depths and breadths), and heights. Areas computed from these measurements in the same manner as those obtained from photographs gave comparable data. These values formed a series of checks against answers obtained from photographic data.

Special equipment was constructed that would make it possible to find the area of any horizontal level of the body directly (Fig. 11). The apparatus consisted of a table that could be raised or lowered to any level. A portion of the table was cut away so that a subject could stand within its limits. The individual to be measured was then clamped in place to prevent body sway. On the table top, a polar planimeter provided with an arched tracer arm could be made to follow the contour of the surface of the body at the selected level. One side of the body contour was traced; then the arched tracer arm was rotated so that the other side of the contour could be completed. The planimetric area was measured at the same landmark used in the photographs and measured in the anthropometry. Planimeter readings, multiplied by a suitable constant, gave the area at the landmark area in standard units of measure. Twenty measurements were completed in about 1-1/2 hours.

Comparisons made between areas determined from photographs by the Weinbach method and areas measured directly from the body show that ordinarily the photographic areas were higher. Presumably, body dimensions, derived from photographs, compute to a larger ellipse than would correspond to actual body areas. Parallax, as indicated above, is a contributing factor in this error. Direct body measurements involving the planimeter depend on the technique and skill of the measurer. The instrument is being changed, however, to provide increased ease in operation.

The plotting of volume and mass distribution relative to height appears to be a new approach in anthropometry, and continued use should have value in characterizing body types. It is probably more important for the present research that the technique provides a way of equating volume of the various regions in living subjects with those of cadavers. Thus, it will allow mass data derived from cadavers to be assigned to regions of living subjects. This in turn will provide the mass data requisite to the development of body mechanics.

Plan for Study of Living Subjects

A series of schedules with suitable blanks for data have been prepared for living subjects. The general content of these is as follows:

1. This form, which is attached to the outside of a folder for each subject, indicates name, address, phone number, time free for work as a model, appointment data, time put in, and the somatotype.

2. This form relates to the first nude examination. It includes a check list of all body postures that will develop skin flexure lines to be marked with a skin pencil. Likewise, it covers photographic data relating to standard somatotype photographs. After processing, a print together with pertinent data is sent to C. W. Dupertuis of Western Reserve University, who responds by postcard with somatotype data. On the basis of these data, subjects are selected or rejected relative to the complete program of study; or, irrespective of the response, the subject may be used for limited special study.

3. Schedule 3 is a blank relating to 84 items covering an anthropometric survey involving both circumferences and measurements of span. The great bulk of the measurements are interrelated dimensions used in the Weinbach technique, in direct body-area measurements, or they relate to measurements made on cadavers.

4. This schedule provides blanks for heights, planimetric readings, conversion factors used to derive body-area measurements, and area measurements. This schedule is used with the area-measuring apparatus mentioned above.

5. The fifth schedule relates to photographic records that involve the orientation of pelvic and thoracic landmarks in different postural positions—standing, seated, recumbent, etc.

6. Schedule 6 relates to a photographic survey of possible positions of the hand and the upper extremity joints in the restrained type of movement. It also relates to restrained movements of the foot in different orientations for the seated body.

7. This schedule deals with volume measurements of extremities by water immersion.

8. The final schedule relates to dynamic aspects of extremity movements.

A somewhat comparable set of schedules for cadaver study has been developed and is now being subjected to trial use.

WORK BEGUN, IN PROGRESS, AND IN PROSPECT

Work at present and that scheduled for the summer months is a continuation of the main problems outlined above or indicated in the previous report as "Work in Prospect." Cadaver work on body segments will be emphasized, but interim data gathering on living subjects will be continued. Minor problems on skin elasticity and on muscle fasciculus dissections will come to a close shortly. Ligaments will not be worked on, at least not in the immediate future. Sawing of frozen unpreserved cadavers will not begin until safety precautions relating to potentially infectious sawdust can be developed to the level of a sterile technique. The principal aim of current and projected work will be (1) gathering data on body links, (2) deriving mechanical data from cadaver segments, and (3) gathering data on living subjects, especially relating to extremity movements and to shoulder and hip axis localization.

EQUIPMENT

The chief item of new equipment was the area-measuring apparatus shown in Fig. 11. Mechanisms for attaching guide lines to the body have been developed for the pelvis and sternal regions (Fig. 9). Appliances for the attachment of strobe lights to the limbs have been constructed and are now ready for trial. Center-of-gravity balance boards have been made for cadaver and living-subject measurement. Certain equipment specifically relating to the study of cadaver parts— pendulum support for the experimental determination of moment of inertia, water tank for the immersion and volume measurement of parts, etc. - are now available. Except for equipment for special uses that may develop as accessory aids, the essential equipment is now complete or has been developed to a state available for testing use.