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A FOUNDATION FOR SYSTEMS ANTHROPOMETRY
Phase II

A FINAL REPORT FOR PHASE II OF CONTRACT #F44620-76-C-0015

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report describes the experimental procedures utilized at Highway Safety Research Institute and The Civil Aeromedical Institute in an investigation of the landmarks, axes systems, and joint properties necessary to describe the human body in three-dimensional space. The study at HSRI utilized three fresh cadavers in the study of the spatial relationship between internal and external landmarks in the lumbar/pelvic/femur region of the body. In addition, the motion characteristics of the hip joint in flexion-extension, abduction-

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) adduction, and internal-external rotation were investigated. The study at CAMI is using 150 male and 150 female osteological specimens from the Hamann-Todd skeletal collection to investigate the three-dimensional variability of landmark locations in the pelvis. Data are presented in tabular and graphical forms.

In general, the results of this program to date can be summarized as follows:

1) Biological variability must be considered as a set of probabilistic phenomena in deterministic biomechanical models.

2) Body position and mobility must be considered simultaneously in three-dimensional space.

3) Data collection and analysis must incorporate the use of anatomical frames of reference defined by functionally significant landmarks in the skeletal system.

4) Body position can be defined by the location of anatomical frames of reference, and body mobility can be defined by relative motion between adjacent anatomical frames of reference.

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In addition, a very unique relationship has developed between this research program and a related program at the Civil Aeromedical Institute in Oklahoma City. Dr. Clyde Snow, Chief of the Physical Anthropology Unit in the Protection and Survival Laboratory, and Dr. Reynolds are investigating the geometry of the human pelvis as a cooperative research program. Without this research arrangement, much of the progress obtained to date in systems anthropometry would have not been possible.

During the preparation of this manuscript, Dr. Robert Hubbard, Mr. Charles Clauser, and Dr. Kenneth Kennedy gave excellent advice which greatly improved the report. We would also like to gratefully acknowledge the expert typing of Arvilla Bolley and Cheryl Luft in the Department of Biomechanics, Michigan State University. In addition, the artistic ability of Doris Sáenz has been greatly appreciated.

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Traditional simulation concepts have considered the body as a series of interconnected rigid "mass-links." The anatomical foundation of this approach was laid by Braune and Fischer (1889, 1892) in their investigation of the biomechanics of body positions assumed by German infantrymen in the 19th century. Their results have led 20th century biomechanicists frequently to use mechanical analogues of human anatomy in their investigations of the dynamic human body. Of those 20th century investigators who continued to study and measure the anthropometric parameters for these mechanical analogues that simulate the human body, Dempster (1955) achieved the most comprehensive results. To advance significantly beyond Dempster's contributions, human body position and mobility must be studied and measured in the three-dimensional frame of reference with a more exact description of joint articulation, and the variation must be statistically analyzed for predictive models. Two-dimensional measurement techniques must be replaced with three-dimensional measurement techniques; the geometric description of human body position must incorporate probability statistics; and body mobility must have a kinematically complete characterization.

The acquisition of data from which an accurate three-dimensional prediction of body position and mobility can be obtained must be based upon functional and stable landmarks. These landmarks are palpable skeletal features that are consistently, not randomly, found on each individual in the population. Skeletal features, suitable for landmark definition, are found at the site of either a muscle's origin or insertion, which is mechanically the site of application of an internally generated force that produces motion of one bone relative to another. Recognition of this relationship in the musculo-skeletal system is important for Systems Anthropometry only in that it provides the rationale for using axes systems based on an anatomical frame of reference. This insight into the etiology of our skeletal geometry may provide the means by which the kinematic properties of the human body are predicted. That is, since human body mobility is a function of muscular "forces" acting upon skeletal "links," the spatial position of the musculo-skeletal system should provide an independent variable which can predict mobility given the time-displacement parameters necessary for kinematic analyzes. This approach is unique to Systems Anthropometry and may provide the means by which predictive models achieve accurate results.

There are two major research questions posed relative to these landmarks. First, is there a defineable relationship between corresponding internal skeletal landmarks and the external projection of that skeletal feature that is located on the skin surface? If such a relationship can be defined, then investigations concerning body position and mobility on living subjects can be directed through the use of skeletal landmarks. In order to conduct such an investigation, a spatial relationship must be defined between corresponding internal and external landmarks.

Second, are these landmarks suitable for defining skeletally-based axes systems through which the effect of intra- and inter-individual differences on body position and mobility can be investigated? In order to accurately describe the position and orientation of a body segment through the use of a three-dimensional axis system, the definition of the axis system should be made using landmarks that are as far apart as possible on a single rigid bone. In addition, these landmarks must be accurately and reproducibly identified on each subject.

Systems Anthropometry has, therefore, approached the study of body position and mobility from the viewpoint that the human body is a three-dimensional system composed of segments that move relative to each other. The basic descriptive mechanism is an anatomical frame of reference unique to each segment. Within these frames of reference, mass distribution properties and relative segment motion properties are located and oriented (Figure 1). The latter parameter is the primary focus for the research conducted under this program. That is, the current research program is investigating segment landmarks, segment axes systems based upon these landmarks, and motion description and prediction of one segment relative to an adjacent segment. In summary, body position will be defined by the location of three-dimensional Cartesian coordinate axes systems based on skeletal landmarks, and body mobility will be defined by the relative motion between these axes systems.

The lumbar/pelvic/femur region has been the first part of the body to be investigated. The pelvis provides a basic skeletal geometry within which motion of the femur (thigh segment) can be described for the kinematically complete six degrees of freedom. The freedom of the hip joint to rotations about three orthogonal axes, and, to some extent, translation, provides a wide range of possible motion paths that are perhaps more extensive than can be represented by a ball-and-socket description. As a result, the mobility of the hip joint contains components that must be described within a probabilistic framework.

In summary, the present investigation is attempting to provide the methodology and selected data suitable for three-dimensional predictive simulations of whole-body position and mobility. These data are used, as pointed out in the 1st Interim Report to the Air Force Office of Scientific Research, in both simulations of impact and acceleration environments as well as workspace design problems.

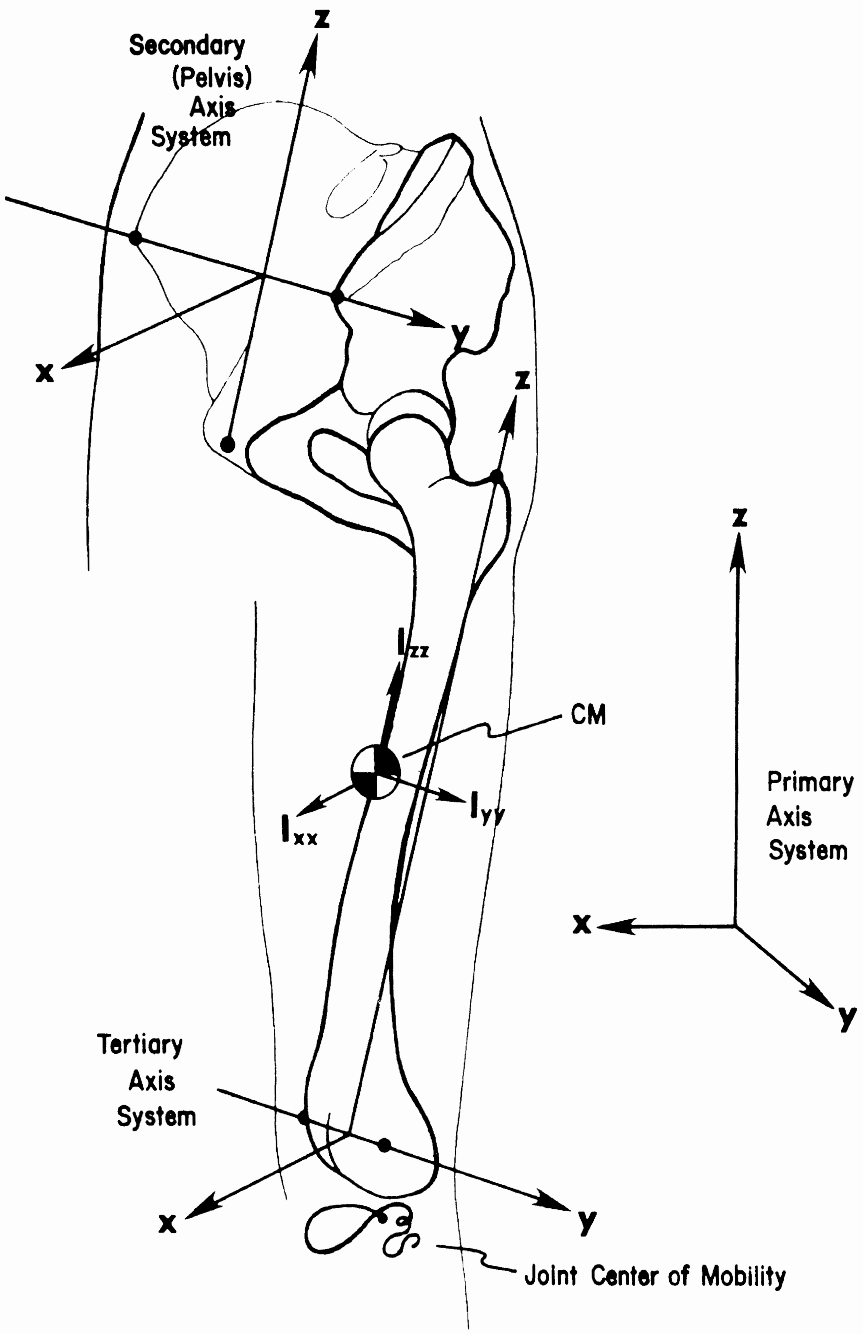


Figure 1. Diagram of Primary, Secondary and tertiary axis systems.

2. RESEARCH METHODOLOGY

2.1 Subjects

At Highway Safety Research Institute (HSRI), an investigation into the relationship between internal skeletal and external surface landmark locations, segment axes systems, and relative segment motion has used fresh cadavers.* In cooperation with Dr. Clyde C. Snow at the Civil Aeromedical Institute (CAMI) in Oklahoma City, osteological specimens, obtained on loan from the Hamann-Todd Skeletal Collection at the Cleveland Museum of Natural History, have been used in the investigation of the variability of skeletal landmarks for axis system definition.

Integration of the results from these two separate studies will utilize an anthropometric body-sizing scheme discussed in the 1st Interim Report. Anthropometric data are collected on each cadaver used in the radiographic investigation of three-dimensional body position and mobility. Similar anthropometric data are available on each cadaver represented in the Hamann-Todd skeletal collection. Thus, within the framework of a statistically defined set of body-size categories, the two samples will be examined and compared thereby making the integration more sensitive to small differences in the data.

2.1.1 HSRI Subjects. Subjects used at HSRI were screened to avoid the use of any cadaver with any obvious pathology. In addition, subjects were selected with a low weight-to-height ratio (or "thinness") to enable improved x-ray imaging of internal target locations and ease of handling. The choice of thin cadavers does not necessarily affect the location of boney "linear" landmarks since there seems to be little relationship

* The protocol for the use of cadavers in this study was reviewed by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings of The University of Michigan Medical Center and follows guidelines established by the U.S. Public Health Service and recommended by the National Academy of Sciences/National Research Council.

between linear boney measurements of boney landmark positions and body weight (see 1st Interim Report). Continuation of the research into the relationship of external surface landmarks and their associated internal skeletal features will, however, require the selection of subjects with soft tissue distribution more accurately representing the variation found in the living population.

Three male caucasian subjects were utilized in radiographic studies at HSRI (Subjects 04, 06, and 07). The subjects weighed 37.7, 43.3 and 42.3 kg ($\bar{x}$ = 41.1 kg) and with statures of 170.1, 165.3 and 177.9 cm ($\bar{x}$ = 171.4 cm) respectively. Subject 04 was 64 years at the time of death which was attributed to "generalized cancer." In addition, this subject had a midline ventral scar extending from the pubis to the tip of the xiphoid and he also had had a L5-S1 laminectomy. Subject 06 was 97 years at the time of death which was attributed to bilateral pneumonia. We received neither the age nor cause of death of subject 07 who appeared to be approximately 80 to 90 years at the time of death. Subjects 04, 06 and 07 were used in the stereo-radiographic investigation of landmarks, axes systems and relative segment motion while subject 07 was additionally used in the cineradiographic imaging study of motion in the hip joint.

Traditional anthropometric measurements were obtained on each of these cadavers. The data are reported in Table 1 and the measurement definition and techniques are included in Appendix A. These data were obtained shortly after the cadaver arrived at the laboratory which in general was within one week of death. There was no rigor mortis evident so that the cadavers were extremely flaccid.

TABLE 1

Traditional anthropometry of fresh cadavers utilized in Phase II x-ray stereo photogrammetry study. (Measurements in cm where applicable)

	Measurement	04	06	07
1.	Weight (KG)	37.7	43.3	42.3
*2.	Stature	170.1	165.3	177.9
3.	Trochanterion Hgt	81.8	76.8	81.2
4.	Symphysion Hgt	83.5	76.5	81.7
5.	ASIS Hgt	76.5	68.3	76.7
6.	Iliocristale Hgt	68.5	64.2	69.0
7.	Substernale Hgt	53.0	52.5	55.9
8.	Mid-Chest Hgt	42.3	40.5	43.7
9.	Suprasternale Hgt	32.2	28.8	32.0
10.	Acromion Hgt	24.2	25.5	25.7
11.	Mastoid Hgt	16.7	15.7	15.9
12.	Tragion Hgt	12.7	12.2	12.5
13.	Tragion Depth	8.5	7.5	
14.	Suprasternale Depth	16.1	15.9	15.2
15.	Mid-Chest Depth	18.1	19.6	17.4
16.	Substernale Depth	16.5	20.9	19.1
17.	ASIS Depth	16.3	13.2	15.2
18.	Symphysion Depth	16.1	17.2	16.1
19.	Suprasternale-Acromion Distance	20.2	20.1	22.4
20.	Biacromial Breadth	28.5	36.0	34.0
21.	Mid-Chest Breadth	27.5	26.1	26.5
22.	Chest Br. at Substernale	27.4	27.7	27.4
23.	Hip Br. at Iliocristale	27.1	28.2	27.5
24.	Bispinous Diameter	20.7	25.0	26.2
25.	ASIS-to-Symphysion Distance	12.6	15.4	14.0

*All composite body heights are measured as a distance from the top of the head.

	Measurement	04	06	07
26.	Bitrochanteric Breadth	30.3	28.4	29.3
27.	Acromion-Radiale Length	32.0	32.5	35.6
28.	Ball of Humerus-Radiale Length	29.3	30.6	33.6
29.	Radiale-Stylion Length	22.7	25.3	27.3
30.	Hand Length	18.6	18.3	19.4
31.	Hand Breadth	7.9	8.0	8.6
32.	Hand Thickness	2.9	2.3	2.6
33.	Wrist Breadth	5.7	5.1	5.5
34.	Forearm Depth	6.9	6.6	7.0
35.	Upper Arm Depth	5.8	8.6	7.4
36.	Femur Length	43.6	46.4	49.2
37.	Fibula Length	36.4	36.0	39.1
38.	Tibia Length		38.2	40.9
39.	Lower Leg Length	43.5	44.4	49.5
40.	Foot Length	26.1	24.2	26.4
41.	Foot Breadth	9.8	8.8	9.9
42.	Minimum Ankle Breadth	5.3	4.1	5.0
43.	Calf Depth	9.6	9.3	9.5
44.	Upper Thigh Breadth	9.3	11.4	12.4
45.	Head Breadth	16.0	16.1	15.4
46.	Head Length	18.6	19.8	20.6
47.	Bitragion Breadth	14.4	14.4	15.1
48.	Bigonial Breadth	10.7	9.6	10.2
49.	Mastoid-Crinion Length	16.4	16.4	15.2
50.	Head Circumference	55.2	58.3	58.0
51.	Mid-Sagittal Arc Length	37.0	32.5	34.0
52.	Bitragion-Coronal Arc Length	34.4	33.3	33.3
53.	Mid-Neck Circumference	31.8	36.9	31.5
54.	Chest Circumference at Mid-Chest	77.2	80.3	76.9
55.	Chest Circumference at Substernale	75.2	81.8	77.8
56.	Hip Circumference at Iliocristale	89.3	71.1	61.5

	Measurement	04	06	07
57.	Buttocks Circumference at Trochanterion	78.9	76.9	77.7
58.	Upper Arm Circumference	14.6	20.5	16.8
59.	Maximum Forearm Circumference	19.5	18.7	19.2
60.	Minimum Wrist Circumference	14.1	13.7	14.6
61.	Upper Thigh Circumference	30.2	37.1	33.1
62.	Maximum Calf Circumference	24.9	25.5	23.2
63.	Minimum Ankle Circumference	18.8	17.0	17.5

2.1.2 CAMI Subjects. Research on the osteological specimens at CAMI is directed at obtaining population parameters on the geometry of the skeleton. The anatomist, Dr. T. W. Todd who collected the skeletons, obtained anthropometric information on each embalmed cadaver whose skeleton was included in the collection. The total collection consists of nearly 3000 human skeletons of documented age, sex, and race.

The osteological specimens currently being measured at CAMI were selected from the total 3000 subjects to match the 1960-1962 HEW US general population height/weight characteristics depicted in Figure 2. Each size-cell has an N=25 that represents as closely as possible the present US population in racial composition and age profile. In addition, each group of specimens sent to CAMI for measurement is representative of the total sample. Thus, the data presented in Table 2 consists of 26 males (average age = 49.4 yrs.) equally distributed among the six size-cells in Figure 2. These dimensions have been defined by Martin (1928) and are presented, as translated from the original German, in Garrett and Kennedy (1971).

The measurements in Table 2 represent the right side of the body. These measurements have been compared by definitions and found to be the same except in those cases that are noted by parenthese around the identification number which corresponds to the measurement definitions in Appendix A. There are additional measurements available on the specimens in the Hamann-Todd collection but only those that are comparable to the measurements obtained on fresh cadavers at HSRI are reported herein.

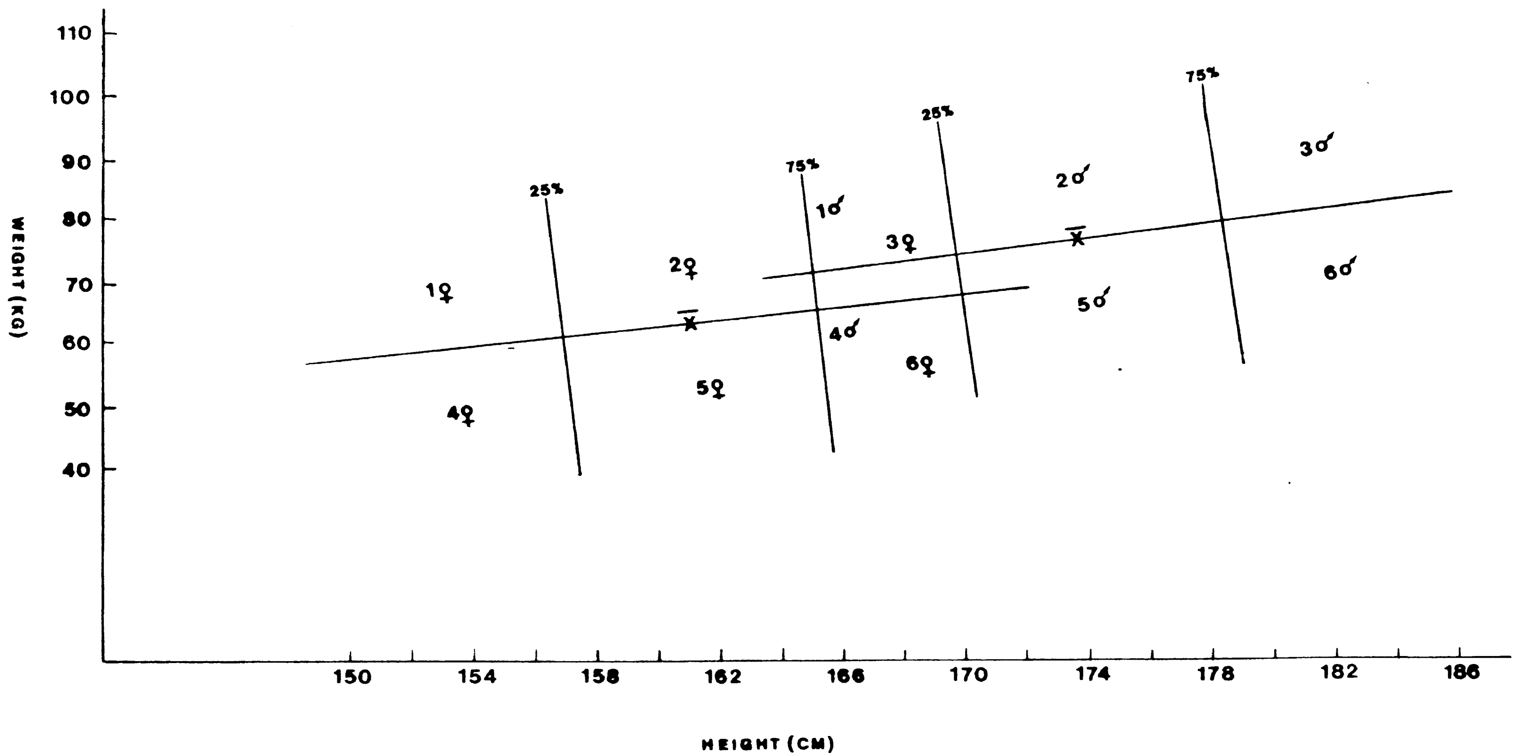


Figure 2. Body size sampling scheme based on 1960-1962 HEW survey.

TABLE 2

Traditional anthropometry of male subjects measured
from Hamann-Todd skeletal collection
(Measurements in cm where applicable)

	Measurement	N	Minimum	Maximum	Mean	Std. Dev.
1a.	Weight (actual in lb.)	26	77.0	208.0	127.4	29.41
1b.	Weight (adjusted in lb.)	26	110.0	254.0	171.7	29.41
*2.	Stature	26	145.2	193.8	173.0	11.17
3.	Trochanterion Hgt.	26	76.9	102.2	90.6	5.75
4.	Symphysion Hgt.	26	74.4	100.9	89.5	5.82
5.	ASIS Hgt.	26	81.1	108.7	96.5	6.42
9.	Suprasternale Hgt.	26	125.9	159.6	142.2	8.60
10.	Acromion Hgt.	26	126.9	166.9	144.2	8.95
20.	Biacronical Breadth	25	27.7	36.1	33.0	2.30
(21-22)	Chest Breadth	26	19.8	32.9	27.3	3.10
23.	Hip Breadth at Iliocristale	26	24.6	31.5	28.9	1.72
24.	Bispinous Diameter	26	19.8	26.4	23.8	1.57
27.	Acromion-Radiale Length	26	28.7	37.8	33.4	2.03
29.	Radiale-Stylian Length	26	20.7	30.0	25.6	1.94
30.	Hand Length	26	16.5	21.7	19.1	1.38
31.	Hand Breadth	26	6.9	9.7	8.0	0.56
(36)	Femur (thigh) Length	26	43.0	56.8	49.4	3.45
(38)	Femur (shank) Length	26	30.9	45.1	38.9	2.96
40.	Foot Length	25	12.8	29.2	24.2	3.01
41.	Foot Breadth	26	7.3	10.8	9.0	0.85
45.	Head Breadth	26	13.4	16.5	15.1	0.82
46.	Head Length	26	17.6	20.4	19.1	0.76
47.	Bitragion Breadth	25	11.4	17.0	12.6	1.04
48.	Bigonial Breadth	26	9.4	13.3	11.1	0.91
50.	Head Circumference	25	52.0	59.3	55.8	1.95

*All composite body heights are measured as a distance from the soles of the feet.

	Measurement	N	Minimum	Maximum	Mean	Std. Dev.
51.	Mid-Sagittal Arc Length	25	31.3	36.8	34.0	1.46
52.	Bitragion-Coronal Arc. L.	25	31.2	36.5	34.3	1.61
(54-55)	Chest Circ.	26	70.5	106.8	86.7	9.94
58.	Upper Arm Circ.	25	16.5	32.4	24.5	4.55
59.	Maximum Forearm Circ.	25	17.3	30.2	23.4	3.17
60.	Minimum Wrist Circ.	25	12.9	18.9	15.9	1.82
61.	Upper Thigh Circ.	25	33.2	64.3	47.2	7.81
62.	Maximum Calf Circ.	25	22.7	42.6	31.4	5.26
63.	Minimum Ankle Circ.	26	16.2	28.6	20.4	3.15

2.2 Three-Dimensional Measurement Techniques.

Measurement techniques employed at both HSRI and CAMI locate points in a three-dimensional Cartesian coordinate frame of reference. These points are anatomical landmarks that will be used to define the position and mobility of the human body. This section will therefore discuss primarily the equipment and characteristics of that equipment relative to what it measures and how accurately it can measure points in three-dimensional space.

2.2.1 HSRI Instrumentation. The basic measurement technique is quantitative stereo-radiography which consists of a pair of stereo-radiographs obtained within a controlled geometry. The x-y coordinate locations of each landmark in the corresponding stereo-pairs are combined in a computerized algorithm to produce the x-y-z coordinate locations of each landmark relative to the film reference system. These three-dimensional data are then transformed into an antomical axis system based on three landmarks on the specimen.

The HSRI x-ray system used in this work was not specifically configured for x-ray stereophotogrammetry. It consisted of a conventional moveable tube head and stand, with a clinical x-ray table and cassette holder. The measurement space of the stereo-radiographs was therefore limited to a 14" x 17" film format which restricted the anatomical region of study to landmarks in the lower lumbar vertebrae, pelvis and upper half of the femur. This was a major limitation to the study since it was impossible to obtain data on the complete thigh segment. The outline of the experiment in Appendix C therefore describes the sequence by which the data were obtained with the facility at HSRI and not the ideal sequence for a stereo-radiographic laboratory dedicated to Systems Anthropometry research.

Since the x-ray system at HSRI was not dedicated to Systems

Anthropometry, frequent re-positioning of the moveable components was a problem. A calibration device, described in the Interim Report, was constructed to serve two purposes: 1) to provide an array of points in space for which true values were available, and 2) to provide a measure of the spread, or repeatability, of reproducing the control points for numerous re-positionings of the x-ray facility components. Three calibration test conditions were studied as follows (See Figure 3):

1) the calibration device was placed directly on the film cassette (Condition I), which was placed on the x-ray table surface; in this case, lines were drawn on the x-ray table surface, and on cassette surfaces to assure, as much as possible, replacement of device and cassette during production of stereopairs;

2) the calibration device was placed on the x-ray table surface (Condition II), and cassettes were placed in the normal cassette holder in the x-ray table; lines on the table to position the device, and markers on the table to position the cassette holder were used; this test condition represented ordinary, normal usage of the x-ray table;

3) the calibration device was placed on a specially constructed table (Condition III), to position subject specimens, and also contained a fixture beneath its surface to hold cassettes in a much more rigid and repeatable position than the normal cassette holder could; this table was clamped to the x-ray table.

In each of the above test conditions, the calibration device was reproduced in three dimensions by stereoradiographic analysis. These included points all in the upper plane, all in the lower plane, and between the upper and lower plane. A total of 270 separate distance determinations for the three test conditions and arrays of points in space was conducted, resulting in

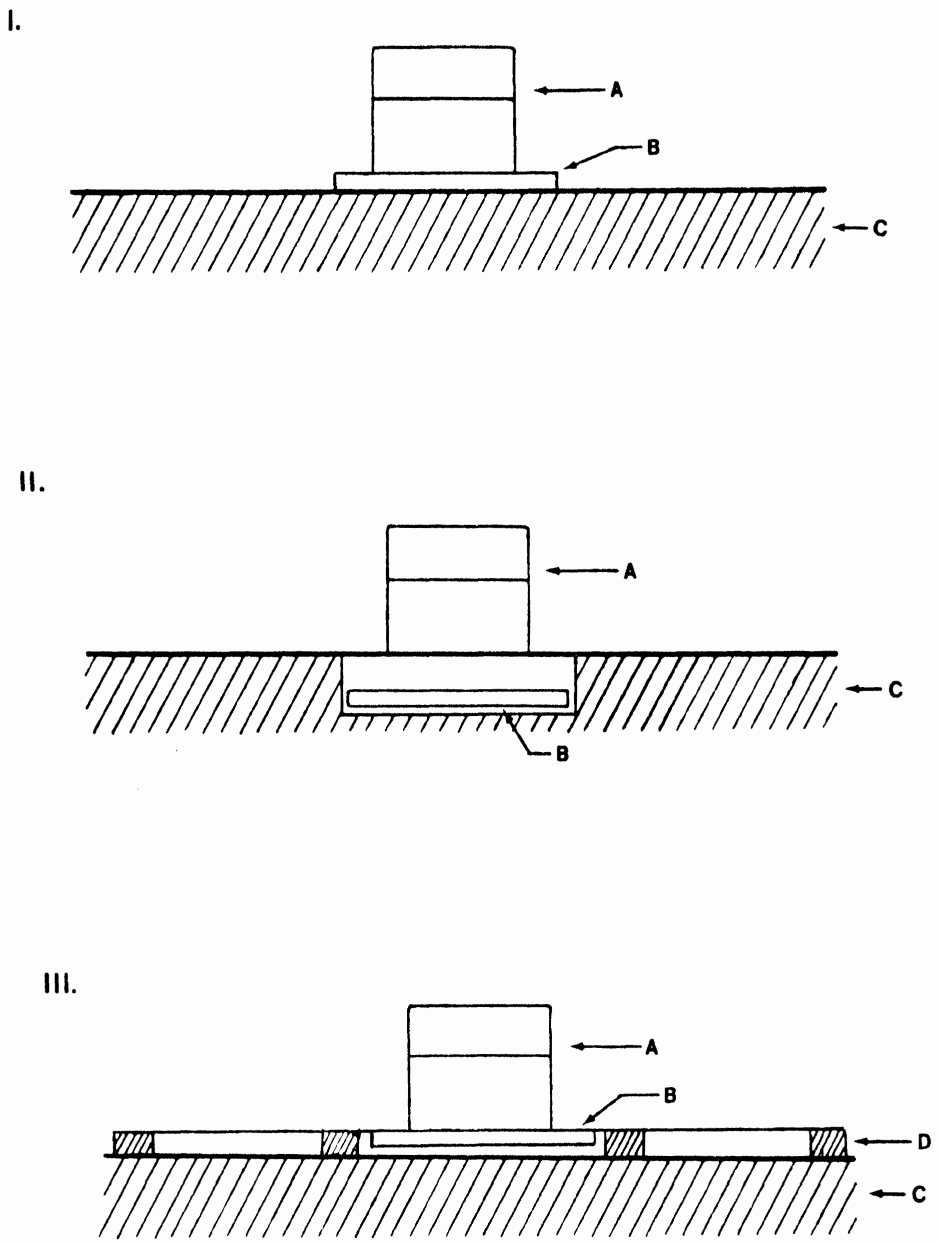


Figure 3. Schematic diagram of placement of calibration device during three test conditions: I, II and III as described in text where A represents the calibration device, B the film cassette, C the clinical X-ray table, and D the HSRI constructed table.

a single mean accuracy* value for each test condition. These values represent the composite of systematic and random error, without attempting to separate the magnitude of each error component. The results, presented in Table 3, show that the effort expended to assure rigid and repeatable positioning of the x-ray cassette did lead to an improvement in the composite accuracy. The third case in Table 3 shows that a 129 mm length in space could be determined to within 3.74 mm, and in many cases, even better than this, which was quite remarkable considering the difficulties encountered in the HSRI x-ray facility. Greater improvement could have been attained had the x-ray tube positioning been controlled more accurately, but this would have required structural modifications that were not feasible in view of the usage circumstances of the HSRI facility. For highly accurate coordinate determination in systems anthropometry, an x-ray facility properly configured and dedicated is required.

The radiographs obtained in this x-ray facility were digitized on a specially constructed light table using a mechanical desk-top digitizer with a resolution of 0.25 mm. The coordinate data were transmitted upon command into either a minicomputer at HSRI or the University of Michigan computer which calculated the three-dimensional coordinates of each landmark. The FORTRAN program is included as Appendix B.

In addition to the above clinical x-ray facility at HSRI, a cine-radiographic system was used to observe hip joint motion in a subject (#07) in order to observe the range and sequence of

*Accuracy is defined here as the ratio of the absolute magnitude of the difference between a measured value and its true value to the true value, expressed as a percent, as follows:

$$\text{Percent accuracy} = \frac{|a' - a|}{a} \times 100$$

where a' is the measured value, and a is the true value.

TABLE 3

Summary of composite error for three calibration conditions.

Test Configuration	N	$\bar{x}$	Minimum	Maximum
1) Calibration device directly on cassette	96	3.4%	1.9%	6.4%
2) Calibration device on x-ray table, cassette in table holder	93	3.4%	1.9%	4.5%
3) Calibration device on fabricated specimen and cassette holder	81	2.9%	1.6%	3.6%

motion of the femur relative to the pelvis. No contrast media or special targeting techniques were used. The radiographic system was designed for obtaining 16 mm motion-picture film data at 1000 frames per second, but for normal joint motion, the system was operated at 64 frames per second with a 16 mm motion-picture camera. The x-ray source was a specially modified x-ray generator to produce smoothed d-c x-ray radiation for high-speed photogrammetric work. The subject was radiographed posterior-anterior onto a 25 cm by 25 cm x-ray-to-light conversion screen consisting of calcium tungstate. The x-ray image on the fluorescent screen is imaged onto the photocathode of a very high gain, 4-stage, magnetically focused image intensifier tube. The output phosphor image was photographed by the Milliken motion picture camera with lens setting of f.95, containing Eastman Double-X negative high-speed motion picture film, ASA 200. This was developed in Acufine at 20^{o}C for 5 minutes. The system is capable of resolving 0.5 mm at 80% contrast. Radiation exposure at the skin surface of the order of 100-milliroentgens for a 1-second sequence of frames, for 2.5 mm of inherent equivalent aluminum filtration.

2.2.2 CAMI Instrumentation. The equipment used to measure landmarks on the osteological specimens consists of a tablet digitizer and desktop computer (Figure 4). This system was modified by attaching a diagraph to the digitizing cursor so that the diagraph's needle-point is centered vertically above the cross-hairs of the cursor at all times. A potentiometer on the diagraph registers the height of the needle-point above the tablet and provides coordinate data on an axis perpendicular to the tablet plane. A pelvic specimen is suspended over the board in a position allowing access to all of the landmarks on the bone. The measurement space is restricted to approximately a 40cm x 35cm cube within which the pelvis must remain movable during the measurements. The diagraph is maneuvered within this space so that the needle is in contact with a landmark. A signal, activated on the cursor, registers in the computer the x-y-z coordinates of the landmark in relation to an origin on the tablet. The spatial location of each landmark is later transformed into an anatomical axis system defined by landmarks on the pelvis. Repeated calibration runs on test specimens reveal an average repeatability within $\pm$ 0.5 mm on known point-to-point linear distances.

In order to locate the approximate center of the femoral head relative to the pelvic specimen, a series of lucite hemispheres were constructed. These hemispheres are center-drilled and marked with two orthogonal axes passing through the center. To obtain the closest possible fit in the acetabulum of each specimen (male and female), the hemispheres were constructed in 2.5 mm increments ranging from 30 cm to 60 cm in diameter. During the measurement procedure, the appropriate hemisphere is fitted to each pelvic specimen and its' center is located in three-dimensional space.

Figure 4. Photograph of measurement instrumentation at CAMI.

3. PHASE II RESEARCH RESULTS

3.1 Investigations involving fresh cadavers at HSRI.

There are three areas of investigation outlined for fresh cadaver subjects. They are:

1) What landmarks (surface and/or skeletal) are suitable for three-dimensional description of the body position and mobility and subsequently what is the geometrical relationship between the internal skeletal landmark and the corresponding external landmark?

2) Which landmarks should be used to define the secondary and tertiary three-dimensional Cartesian coordinate axes systems?

3) Where does the body move and how should this movement be modeled such that it is in a format that is compatible with predictive statistics?

The results of our investigation at HSRI will therefore be reported within the context of how these questions were addressed at HSRI and are intended to represent a methodology rather than experimental results.

3.1.1 Surface-internal landmark correlation investigation.

The cadaver was placed in a supine position on the x-ray table and landmarks (Appendix D) were marked on the skin with lead crosses. The landmarks, right and left anterior superior iliac spine, symphysion, right and left pubic tubercles and the right greater trochanter of the femur, were taped in place and the first stereo-pair was then obtained. Next, without moving the body, the markers were removed; skeleton exposed at the approximate landmark location; and the lead marker was glued to the skeleton with a methyl-2 cyanoacrylate adhesive. The incision was closed and a second stereo-pair was obtained to determine the spatial relationship between corresponding internal and external landmarks. In addition to the above landmarks, two more markers were glued to the greater trochanter. In the case of subject 06, a small nail was driven into the head of the femur and for subject 07 two small nails were driven into the head of the femur (Figure 5). These markers were placed on the femur to provide comparative paths of motion at a site closer to the traditional location of the hip joint center rotation.

After taking the anterior-posterior stereo-radiographs for investigating landmarks on the ventral side, the cadaver was then placed in a prone position and a similar procedure was followed to investigate landmarks on the dorsal side. The three landmarks were one each over the right and left posterior superior iliac spines (PSIS) and one on a line passing through the right and left PSIS landmarks overlying the middle of the spinal column. A posterior-anterior stereo-radiographic pair of x-rays were obtained of these three landmarks which also includes the landmarks in situ on the ventral side. Next, internal landmarks were exposed by dissection and lead markers were placed on the dorsal skeletal landmarks. These landmarks, the dorsal spine of the fifth lumbar vertebra, right and left posterior superior iliac spines, and the first dorsal spine of the sacral body. The incisions were closed and a stereo-pair was obtained thereby concluding this section of the investigation.

The three-dimensional Cartesian coordinates for each landmark are located relative to the secondary axis system defined by the skeletal landmarks--right and left anterior superior iliac spines and symphysion. The axis system is defined by a line passing through the right and left anterior superior iliac spines for the "y-axis"; the "z-axis" passes through Symphysion and is perpendicular to the "y-axis"; the "x-axis" is a normal to the "y-z plane" and it passes through the point of intersection of the y- and z-axes. The origin of the secondary axis system is

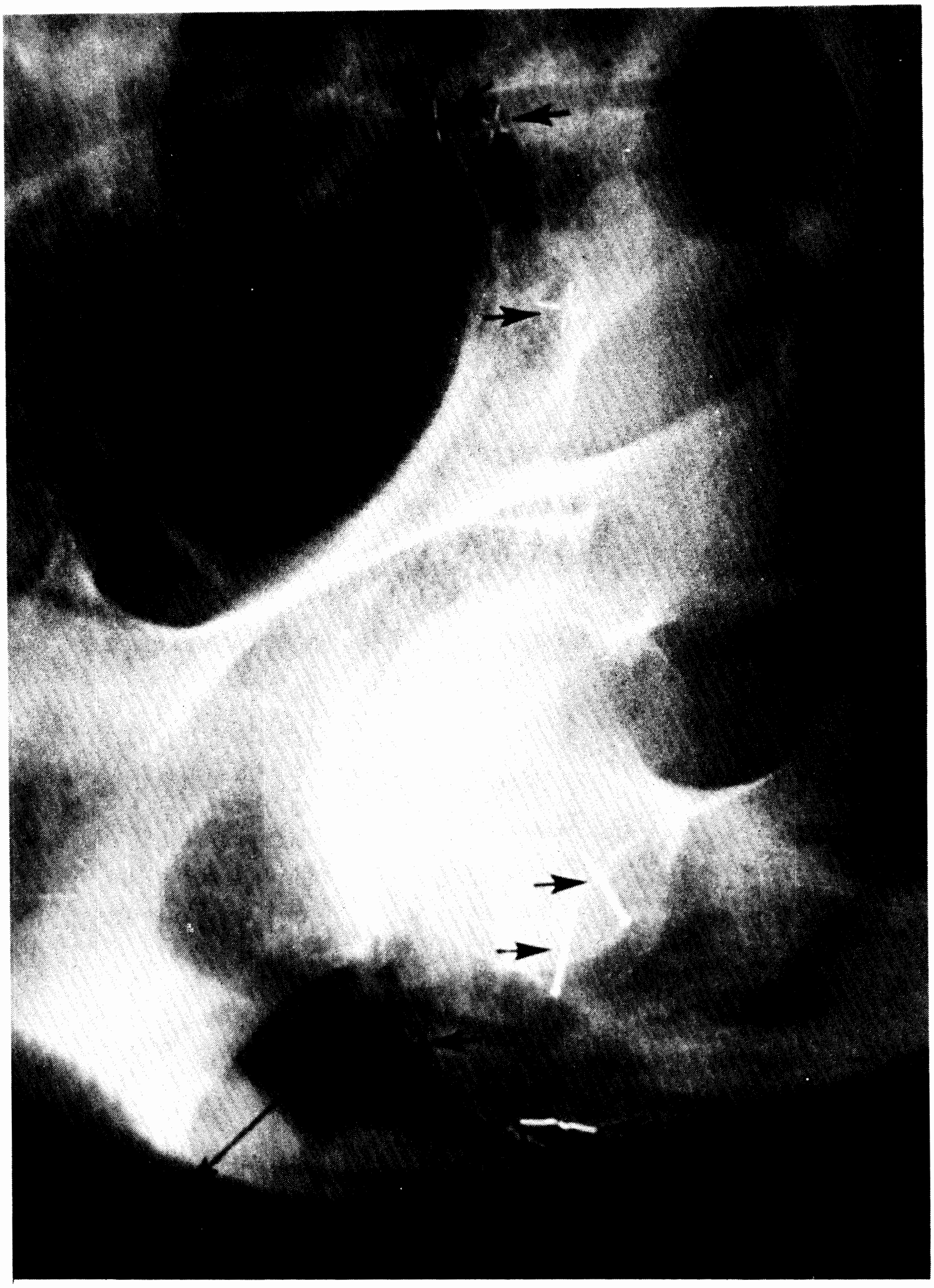


Figure 5. Photocopy of radiograph showing landmarks in the hip region of subject 07.

defined by the intersection of the three orthogonal axes. This right-handed axis system has its' +x direction from posterior to anterior, +y direction from right lateral to left lateral, and +z direction from inferior to superior.

Operationally, this skeletal axis system is not present in the first stereo-pair obtained of the ventral surface landmarks. Since the cadaver is not moved between stero-pairs of the external and internal landmarks on the ventral side, the external landmark locations can be transformed later into the skeletal axis system coordinates defined in the second stereo-pair obtained. Figure 6 illustrates the definition of the vector and direction angles. The data in Table 4 are presented in centimeters distance from the internal to the external landmark and direction degrees of the vector in the skeletal axis system described above. The mid-spine dorsal landmark is the only case in which there is only one external surface landmark located relative to two internal skeletal landmarks.

Upon completion of all measurements on each cadaver, the appropriate skeletal material with markers still glued rigidly in place on the boney feature was excised from the cadaver. These bones with markers in place will be compared to those used in the CAMI pelvic study to insure comparability of landmark definition.

3.1.2 Investigation of relative segment motion at the hip joint. The total leg of each cadaver was sequentially positioned to produce motion at the hip joint. Stereo-radiographs were obtained of the hip joint as the total leg was moved in increments of 10^{0} to 30^{0} angular displacement of the total leg. An effort was made to move the limb in the appropriate cardinal plane. Therefore, for the motion of abduction-adduction, the limb movement was restricted primarily to the frontal plane. Limb movement was restricted primarily to the transverse plane

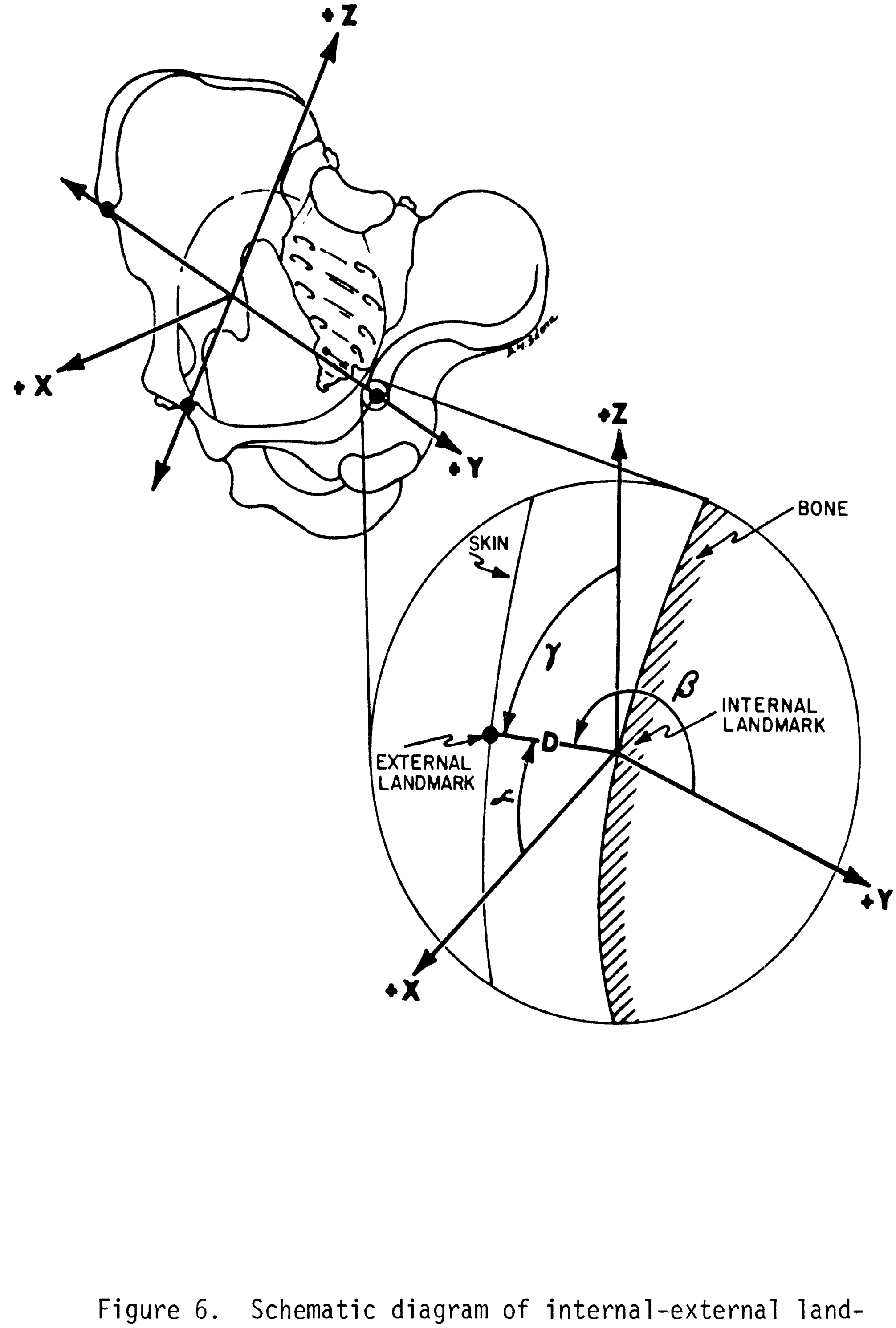


Figure 6. Schematic diagram of internal-external landmark geometry within the pelvic axis system.

TABLE 4

Spatial geometry between internal and external landmarks

Subject 06		VECTOR		
Internal-to-External	Length(cm)	Direction	Angles	(degrees)
		αβγ	αβγ	αβγ
RT. ASIS	0.20	53.81	129.77	60.52
LT. ASIS	1.06	89.46	143.45	126.54
SYMPHYSION	1.13	59.14	91.52	30.91
RT. TUBEROSITY	1.23	52.94	142.94	89.53
LT. TUBEROSITY	----	-----	------	-----
RT. TROCHANTERION	2.28	84.41	162.27	73.23
RT. PSIS	1.63	99.9	157.05	69.52
LT. PSIS	1.77	128.38	112.30	133.31
L5 to Midspine	3.69	138.38	112.30	133.31
S1 to Midspine	1.59	116.21	153.61	87.11

Subject 07				
RT. ASIS	0.94	28.91	70.67	69.37
LT. ASIS	1.45	19.75	86.43	70.6
SYMPHYSION	1.18	19.28	71.15	93.90
RT. TUBEROSITY	0.66	26.34	69.55	105.87
LT. TUBEROSITY	0.86	44.67	45.61	94.01
RT. TROCHANTERION	1.69	136.69	98.85	48.05
RT. PSIS	0.55	124.29	58.19	50.49
LT. PSIS	0.86	108.89	59.42	37.08
L5 to Midspine	2.99	127.56	77.03	129.49
S1 to Midspine	0.95	140.95	56.93	139.49

for internal-external rotation of the hip joint, and limb movement was restricted primarily to a para-sagittal plane for flexion-extension of the hip joint. Thus, femur motion was not well controlled in all planes during a particular motion.

As outlined in the Interim Report, segment motion of the thigh relative to the pelvis should be measured by tracking a moving three-dimensional Cartesian coordinate frame of reference (tertiary axis system) based on three landmarks defined on the femur relative to a fixed, unmoving frame of reference in the pelvis (secondary axis system). The axis system for the thigh should be defined by three landmarks on the femur as far apart from each other as possible. However, since the distal end of the femur and the superior surface of the pelvis were not both visible in a 14" x 17" radiographic film format, three landmarks on the greater trochanter were chosen. As an indication of measurement error, for these landmarks to be used in constructing an axis system, the average area within the triangle defined by the three points in all stereo-pairs was computed for subjects 04, 06, and 07. The area values, 2.021, 0.656, and 1.400 cm^2 respectively, are small indicating that the magnitude of the quantities approaches the magnitude of the measurement error discussed in a preceding section. The residual of the difference between the average and each individual area value were regressed against the position of the thigh defined as the positive and negative radians either side of the initial starting position in the approximate anatomical position. The results of this analysis, presented in Table 5, indicate that measurement error of the motion in the sagittal and frontal planes appear to be generally random, but there appears to be a small systematic error in the measurement of these points moving in the transverse plane.

The coordinate data for each target on each cadaver sub-

TABLE 5

Statistical analysis of error in
trochanter landmarks' location.

Primary Plane of motion	N	Regression	SE	"r"
Sagittal (Flexion)	13	y = .003x + .072	0.156	.013
Frontal (Abduction)	19	y = .008x + .043	0.167	.012
Transverse (Rotation)	19	y = .019x + .089	0.130	.449

ject is presented in Tables 6-8. Measurements were obtained on the left side for subject 04 and on the right side for subjects 06 and 07. These coordinate data are all located in the secondary axis system defined in the pelvis by the right and left anterior superior iliac spines and symphysion. As the project progressed from subject 04 to 07, other landmarks were added until in the last subject (07) seventeen landmarks were in place on the skeleton for each stereo-radiograph for the motion studies.

The three-dimensional Cartesian coordinates are extremely difficult to interpret in their digital form. Therefore, plots were generated by computer in order to visualize the projected path of motion of the femur relative to the secondary axis system for all subjects. The projected path of Trochanterion for flexion-extension in the sagittal (x-y) plane is plotted in Figure 7. The same point for abduction-adduction is plotted in the frontal plane projection (y-z plane) in Figure 8; and for internal-external rotation of motion, the point is seen projected in the Transverse plane (x-y plane) in Figure 9. A preliminary visual inspection of the data appears to suggest that a ball-and-socket model will explain some of the motion characteristics in these plots. Since the femur was not restricted to motion about a single axis, the projected paths in Figure 7-9 reflect the total motion in the hip for the six kinematical degrees of freedom.

Cineradiographic films of the hip joint during flexion and abduction of the thigh support this model as a reasonable first approximation of the hip joint. Figures 10a-10n provide a sample of selected still photographs made from the abduction sequence in which the femur appears to rotate about at least two axes passing through the hip joint. These cineradiographs suggest that the complete three dimensional kinematic description of the hip joint

TABLE 6

3-D anthropometry for subject 04 in
x-ray stereo-photogrammetry study
(values in cm relative to secondary axis system)

SUBJECT 04

ADDUCTION - ABDUCTION
(of left leg)

		ADDUCTION		ABDUCTION		
		-15°	0°	10°	20°	30°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00
	Y	-10.67	-10.75	-10.60	-10.65	-10.65
	Z	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00
	Y	9.91	9.98	9.76	10.09	9.99
	Z	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00
	Z	-8.08	-8.12	-8.02	-8.08	-8.09
RT PUBIC TUBEROSITY	X	0.26	0.29	0.36	-0.15	-0.13
	Y	-3.02	-3.06	-2.94	-3.00	-3.02
	Z	-8.79	-8.83	-8.74	-8.79	-8.82
LT PUBIC TUBEROSITY	X	0.45	0.34	0.11	-0.10	0.26
	Y	1.93	1.91	1.96	1.99	1.91
	Z	-8.81	-8.88	-8.80	-8.91	-8.89
MEDIAL TROCHANTER	X	-8.83	-10.10	-9.95	-11.43	-11.09
	Y	12.94	12.90	11.88	13.06	12.22
	Z	-10.16	-8.91	-8.14	-7.44	-7.12
LATERAL TROCHANTER	X	-7.38	-8.96	-8.75	-10.76	-10.20
	Y	14.52	14.79	13.78	15.15	14.19
	Z	-10.71	-9.27	-8.12	-7.04	-6.55
SUPERIOR TROCHANTER (TROCHANTERION)	X	-7.78	-9.19	-8.98	-10.16	-10.04
	Y	13.42	13.32	11.97	12.95	12.07
	Z	-8.61	-7.43	-6.64	-5.87	-5.57

TABLE 6 (con't)

SUBJECT 04

FLEXION
(of left leg)

		0°	20°	40°	60°	80°	100°	120°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-11.51	-11.73	-11.60	-11.72	-11.56	-11.09	-11.48
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	10.09	9.35	9.61	9.88	9.39	9.93	9.55
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-8.14	-8.17	-8.16	-8.21	-8.19	-8.11	-8.12
RT PUBIC TUBEROSITY	X	0.19	0.07	0.15	0.15	0.10	0.23	0.13
	Y	-3.00	-3.53	-3.11	-3.20	-3.29	-2.78	-3.26
	Z	-8.82	-8.81	-8.85	-8.91	-8.85	-8.85	-8.78
LT PUBIC TUBEROSITY	X	0.26	0.15	0.18	0.19	0.15	0.26	0.25
	Y	2.03	1.66	1.83	1.83	1.53	1.96	1.90
	Z	-8.92	-8.92	-8.89	-8.95	-8.89	-8.86	8.88
MEDIAL TROCHANTER	X	-7.11	-6.52	-4.87	-3.69	-2.74	-2.03	-1.56
	Y	15.85	14.41	15.16	15.44	14.67	15.15	15.66
	Z	-9.79	-10.59	-11.21	-11.34	-11.00	-10.86	-10.21
LATERAL TROCHANTER	X	-8.62	-8.10	-6.54	-5.05	-3.56	-2.39	-1.45
	Y	13.95	13.04	13.28	14.10	13.31	13.27	14.09
	Z	-9.28	-10.56	-11.64	-12.36	-12.39	-12.28	-11.67
SUPERIOR TROCHANTER (TROCHANTERION)	X	-7.48	-7.47	-6.43	-5.61	-4.83	-4.06	-3.38
	Y	14.34	12.84	14.10	14.30	13.46	13.50	14.01
	Z	-7.81	-8.70	-9.85	-10.45	-10.80	-11.21	-10.96

TABLE 6 (con't)

SUBJECT 04

ROTATION
(of left leg)

		MEDIAL ROTATION			LATERAL ROTATION		
		60°	30°	0°	30°	60°	90°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-10.69	-10.62	-10.72	-10.53	-10.79	-10.72
	Z	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00
	Y	10.07	9.82	9.85	9.75	10.02	10.03
	Z	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-8.04	-8.01	-8.08	-7.94	-8.12	-8.10
RT PUBIC TUBEROSITY	X	0.23	0.11	0.35	0.11	0.10	-0.07
	Y	-3.06	-2.99	-3.08	-2.94	-3.04	-2.99
	Z	-8.76	-8.74	-8.80	-8.66	-8.86	-8.85
LT PUBIC TUBEROSITY	X	0.27	0.51	0.40	0.19	0.26	-0.05
	Y	1.90	1.88	1.86	1.88	1.94	1.98
	Z	-8.84	-8.73	-8.82	-8.68	-8.88	-8.85
MEDIAL TROCHANTER	X	-10.53	-7.77	-10.39	-10.63	-11.19	-11.70
	Y	15.76	13.96	11.64	10.83	10.91	10.18
	Z	-9.35	-8.93	-8.73	-8.02	-8.13	-7.86
LATERAL TROCHANTER	X	-9.45	-6.21	-9.39	-10.21	-10.89	-11.36
	Y	17.09	15.24	13.63	12.92	13.13	12.41
	Z	-9.84	-9.37	-9.10	-8.34	-8.34	-7.98
SUPERIOR TROCHANTER (TROCHANTERION)	X	-9.35	-6.70	-9.38	-9.46	-10.26	-10.54
	Y	15.63	13.94	12.18	11.39	11.57	10.85
	Z	-7.81	-7.47	-7.29	-6.63	-6.67	-6.38

TABLE 7

3-D anthropometry for subject 06 in x-ray stereo-photogrammetry study
(values in cm relative to secondary axis system)

SUBJECT 06

ADDUCTION - ABDUCTION
(of right leg)

		ADDUCTION				ABDUCTION					
		15°	10°	5°	0°	5°	10°	15°	20°	25°	30°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-12.01	-12.24	-12.16	-12.33	-11.96	-11.89	-11.97	-11.93	-11.86	-11.86
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	12.57	12.56	12.58	12.53	12.72	12.63	12.65	12.63	12.65	12.66
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-9.59	-9.64	-9.62	-9.59	-9.68	-9.61	-9.66	-9.67	-9.65	-9.70
RT PUBIC TUBEROSITY	X	-0.29	-0.23	-0.24	-0.04	-0.10	-0.43	-0.33	-0.31	-0.27	-0.15
	Y	-2.10	-2.15	-2.08	-2.10	-2.04	-2.08	-2.09	-2.12	-2.04	-2.08
	Z	-9.74	-9.78	-9.79	-9.79	-9.84	-9.75	-9.79	-9.80	-9.77	-9.84
LT PUBIC TUBEROSITY	X	-0.54	-0.45	-0.25	-0.24	-0.39	-0.52	-0.35	-0.39	-0.23	-0.16
	Y	2.59	2.62	2.65	2.65	2.68	2.61	2.60	-2.56	2.68	2.59
	Z	-9.64	-9.68	-9.72	-9.68	-9.72	-9.66	-9.73	-9.73	-9.71	-9.80
RT PSIS	X	-13.12	-12.98	-13.31	-13.10	-13.22	-13.43	-13.17	-13.00	-13.30	-13.45
	Y	-3.09	-3.93	-3.74	-4.30	-2.81	-2.78	-2.87	-3.02	-2.68	-2.77
	Z	3.06	2.94	2.97	2.63	3.11	3.21	3.13	3.06	2.75	3.06
LT PSIS	X	-13.28	-13.38	-13.25	-13.14	-13.36	-13.24	-13.25	-12.86	-13.49	-13.32
	Y	3.76	2.98	3.24	2.71	4.12	4.12	3.99	3.89	4.18	4.18
	Z	3.18	3.11	3.03	2.73	3.24	3.27	3.22	3.15	2.88	3.15

TABLE 7 (con't)

SUBJECT 06

ADDUCTION - ABDUCTION (con't)
(of right leg)

		ADDUCTION				ABDUCTION					
		15°	10°	5°	0°	5°	10°	15°	20°	25°	30°
L5 DORSAL SPINE	X	-10.46	-10.76	-10.81	-11.06	-10.68	-10.77	-10.56	-10.60	-11.18	-11.01
	Y	0.29	-0.44	-0.25	-0.76	0.57	0.57	0.48	0.31	0.61	0.58
	Z	5.96	5.96	5.96	5.78	6.12	6.14	6.08	6.05	5.81	6.06
S1 DORSAL SPINE	X	-12.37	-12.84	-12.61	-12.62	-12.51	-12.61	-12.38	-12.18	-13.14	-12.74
	Y	0.26	-0.59	-0.30	-0.89	0.53	0.55	0.42	0.31	0.57	0.61
	Z	3.37	3.37	3.30	3.04	3.45	3.53	3.42	3.37	3.20	3.39
LATERAL TROCHANTER	X	-8.04	-8.57	---	-8.10	-8.31	-8.65	-7.93	-8.85	-8.11	-8.87
	Y	-13.34	-14.05	---	-14.46	-13.28	-13.08	-12.90	-12.89	-12.36	-12.29
	Z	-8.34	-8.00	---	-7.93	-7.06	-6.65	-6.17	-5.79	-5.85	-5.32
MEDIAL TROCHANTER	X	-7.19	-7.93	-7.60	-7.15	-7.40	-7.71	-7.19	-8.20	-7.89	-7.64
	Y	-12.78	-13.51	-13.29	-13.80	-12.80	-12.64	-12.64	-12.64	-12.29	-12.06
	Z	-8.77	-8.46	-8.25	-8.42	-7.64	-7.26	-6.81	-6.40	-6.36	-5.99
SUPERIOR TROCHANTER (TROCHANTERION)	X	-7.54	-8.27	---	-7.84	-8.24	-8.32	-7.53	-8.62	-8.59	-8.67
	Y	-12.80	-13.43	---	-13.76	-12.55	-12.33	-12.04	-12.03	-11.58	-11.39
	Z	-7.36	-7.04	---	-7.00	-6.22	-5.88	-5.56	-5.17	-5.18	-4.84
NAIL HEAD	X	-6.46	-7.17	-7.37	-6.73	-6.88	-7.29	-6.73	-7.67	-6.84	-7.37
	Y	-9.88	-10.49	-10.35	-10.69	-9.67	-9.58	-9.65	-9.73	-9.38	-9.53
	Z	-6.72	-6.56	-6.47	-6.68	-6.25	-6.04	-6.02	-5.81	-6.11	-5.97
NAIL POINT	X	-6.45	-6.86	-6.84	-6.75	-7.25	-7.01	-6.57	-7.30	-6.58	-7.36
	Y	-9.37	-9.90	-9.74	-10.14	-9.30	-9.12	-9.08	-9.12	-8.68	-8.69
	Z	-7.80	-7.70	-7.65	-7.77	-7.32	-7.16	-7.13	-6.92	-7.09	-6.79

TABLE 7 (con't)

SUBJECT 06

ROTATION
(of right leg)

		MEDIAL ROTATION					LATERAL ROTATION			
		30°	15°	0°	15°	30°	45°	60°	75°	90°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-11.88	-11.86	-11.87	-11.98	-11.78	-12.31	-11.83	-11.85	-11.90
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	12.70	12.61	12.68	12.65	12.67	12.46	12.67	12.70	-12.58
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-9.67	-9.59	-9.61	-9.67	-9.62	-9.66	-9.59	-9.62	-9.59
RT PUBIC TUBEROSITY	X	-0.65	-0.39	-0.23	-0.13	-0.67	-0.40	-0.33	-0.22	-0.35
	Y	-2.11	-2.13	-2.06	-2.11	-1.77	-1.87	-2.10	-2.08	-2.11
	Z	-9.76	-9.72	-9.75	-9.83	-9.69	-9.80	-9.72	-9.76	-9.73
LT PUBIC TUBEROSITY	X	-0.58	-0.36	-0.19	-0.46	-0.61	-0.44	-0.43	-0.35	-0.35
	Y	2.60	2.61	2.61	2.60	2.58	2.50	2.60	2.60	2.56
	Z	-9.71	-9.66	-9.67	-9.70	-9.63	-9.71	-9.67	-9.70	-9.64
RT PSIS	X	-13.31	-13.12	-13.28	-12.90	-13.80	-13.36	-13.21	-13.58	-13.20
	Y	-2.82	-2.87	-2.79	-2.95	-2.53	-4.06	-2.55	-2.70	-3.04
	Z	3.13	3.03	2.80	3.27	3.22	3.06	2.99	2.83	3.03
LT PSIS	X	-13.37	-13.28	-13.63	-12.98	-13.79	-13.52	-13.44	-13.55	-13.08
	Y	4.09	4.05	4.07	3.97	4.34	2.86	4.36	4.24	3.87
	Z	3.23	3.11	2.94	3.34	3.31	3.20	3.14	2.92	3.08
L5 DORSAL SPINE	X	-10.98	-10.76	-11.02	-10.41	-11.07	-11.04	-11.05	-11.18	-10.76
	Y	0.54	0.51	0.57	0.41	0.80	-0.57	0.76	0.65	0.36
	Z	6.13	6.01	5.86	6.16	6.12	6.10	6.05	5.88	6.01

TABLE 7 (con't)

SUBJECT 06

ROTATION (con't)
(of right leg)

		MEDIAL ROTATION					LATERAL ROTATION			
		30°	15°	0°	15°	30°	45°	60°	75°	90°
S1 DORSAL SPINE	X	-12.75	-12.55	-12.72	-12.39	-12.97	-12.44	-12.65	-12.88	-12.65
	Y	0.52	0.44	0.51	0.37	0.78	-0.27	0.78	0.66	0.28
	Z	3.47	3.37	3.16	3.60	3.54	3.37	3.35	3.18	3.41
LATERAL TROCHANTER	X	-5.56	-7.14	---	---	-9.55	-10.26	-9.92	-10.13	-10.07
	Y	-13.85	-13.90	---	---	-12.38	-9.88	-12.12	-12.11	-12.12
	Z	-8.00	-7.65	---	---	-6.72	-6.67	-6.65	-6.78	-6.57
MEDIAL TROCHANTER	X	-5.17	-6.21	-6.89	-7.86	-8.70	-8.50	-8.97	-9.06	-8.91
	Y	-13.04	-13.10	-12.98	-12.41	-12.11	-13.11	-11.91	-11.94	-11.96
	Z	-8.41	-8.18	-8.00	-7.50	-7.32	-7.44	-7.23	-7.38	-7.19
SUPERIOR TROCHANTER (TROCHANTERION)	X	-5.77	-6.99	---	-8.02	-9.12	-8.93	-9.41	-9.38	-9.33
	Y	-13.24	-13.20	---	-8.78	-11.74	-12.71	-11.48	-11.46	-11.45
	Z	-7.02	-6.73	---	-6.13	-5.96	-6.08	-5.94	-6.08	-5.86
NAIL HEAD	X	-6.52	-7.24	-6.69	-6.57	-7.60	-7.43	-7.76	-7.92	-7.38
	Y	-9.85	-9.92	-9.77	-9.63	-9.31	-10.36	-9.37	-9.36	-9.44
	Z	-6.57	-6.31	-6.44	-6.25	-6.14	-6.29	-6.20	-6.32	-6.27
NAIL POINT	X	-6.14	-6.97	-6.75	-6.49	-7.35	-7.63	-7.41	-7.78	-7.30
	Y	-9.75	-9.76	-9.49	-9.14	-8.68	-9.34	-8.67	-8.65	-8.69
	Z	-7.71	-7.52	-7.58	-7.36	-7.21	-7.30	-7.24	-7.30	-7.23

TABLE 8

3-D anthropometry for subject 07 in x-ray stereo-photogrammetry study
(values in cm relative to secondary axis system)

SUBJECT 07

ABDUCTION
(of right leg

		0°	5°	10°	15°	20°	35°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-12.79	-12.86	-12.82	-13.01	-12.69	-13.04
	Z	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00
	Y	13.29	13.26	13.22	13.12	13.18	13.15
	Z	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-5.32	-5.31	-5.29	-5.31	-5.30	-5.34
SUPERIOR SYMPHYSION	X	-0.86	-1.06	-1.03	-0.94	-0.92	-1.21
	Y	0.14	0.11	0.11	0.03	0.14	0.03
	Z	-4.49	-4.47	-4.45	-4.49	-4.49	-4.45
RT PUBIC TUBEROSITY	X	0.4	0.21	0.18	0.09	0.11	0.00
	Y	-2.24	-2.27	-2.28	-2.29	-2.27	-2.29
	Z	-6.15	-6.12	-6.09	-6.12	-6.08	-6.14
LT PUBIC TUBEROSITY	X	0.25	0.13	0.14	0.12	-0.02	-0.14
	Y	2.81	2.79	2.84	2.79	2.76	2.79
	Z	-5.98	-5.95	-5.94	-5.95	-5.92	-5.95
MEDIAL TROCHANTER	X	-9.00	-9.22	-8.83	-9.08	-8.70	-10.55
	Y	-12.66	-12.87	-12.76	-13.62	-12.72	-12.51
	Z	-4.98	-4.54	-4.08	-3.67	-3.32	-3.51
LATERAL TROCHANTER	X	-10.43	-10.92	-10.10	-10.19	-9.97	-11.94
	Y	-12.96	-13.14	-12.94	-13.87	-12.93	-12.38
	Z	-4.37	-3.84	-3.42	-3.01	-2.65	-3.25

TABLE 8 (con't)

SUBJECT 07

ABDUCTION (con't)
(of right leg)

		0°	5°	10°	15°	20°	35°
SUPERIOR TROCHANTER (TROCHANTERION)	X	-9.59	-10.09	-9.52	-9.54	-9.81	-11.09
	Y	-11.67	-11.67	-11.32	-12.04	-11.10	-10.37
	Z	-2.85	-2.49	-2.22	-1.95	-1.70	-2.53
SUP. NAIL HEAD	X	-6.90	-7.21	-6.79	-6.65	-6.47	-7.76
	Y	-10.80	-11.02	-10.81	-11.40	-10.75	-11.00
	Z	-5.07	-4.80	-4.57	-4.37	-4.16	-3.85
SUP. NAIL POINT	X	-6.57	-6.98	-6.41	-6.48	-6.54	-7.09
	Y	-9.64	-9.87	-9.73	-10.37	-9.82	-10.18
	Z	-5.38	-5.25	-5.16	-5.02	-4.86	-4.65
INF. NAIL HEAD	X	-6.01	-6.41	-5.89	-6.05	-5.95	-6.45
	Y	-9.80	-10.15	-10.06	-10.71	-10.20	-10.76
	Z	-6.12	-5.94	-5.82	-5.65	-5.44	-5.01
INF. NAIL POINT	X	-6.84	-7.00	-7.06	-7.00	-6.85	-6.93
	Y	-9.01	-9.29	-9.19	-9.83	-9.26	-9.69
	Z	-5.46	-5.44	05.36	-5.28	-5.19	-5.19
RT PSIS	X	-14.23	-14.38	-14.35	-14.40	-14.88	-14.43
	Y	-2.99	-3.19	-2.96	-3.97	-2.80	-3.82
	Z	5.19	5.02	4.84	4.92	4.90	5.17
LT PSIS	X	-14.54	-14.59	-14.89	-14.76	-14.83	-14.45
	Y	5.33	5.14	5.42	4.38	5.50	4.50
	Z	4.96	4.73	4.64	4.70	4.61	4.87
L5 DORSAL SPINE	X	-12.49	-12.80	-13.02	-12.71	-12.69	-12.56
	Y	0.65	0.46	0.71	-0.24	0.81	-0.14
	Z	7.72	7.58	7.47	7.48	7.39	7.67
S1 DORSAL SPINE	X	-13.72	-14.05	-14.06	-14.14	-13.88	-13.97
	Y	0.86	0.65	0.91	-0.12	1.00	0.01
	Z	5.81	5.64	5.51	5.58	5.45	5.82

TABLE 8 (con't)

SUBJECT 07

FLEXION
(of right leg)

		0°	10°	20°	30°	45°	60°	70°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-13.06	-12.86	-13.03	-13.00	-12.79	-13.08	-13.00
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	13.15	13.20	13.18	13.17	13.26	13.06	13.25
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-5.33	-5.36	-5.30	-5.32	-5.31	-5.34	-5.33
SUPERIOR SYMPHYSION	X	-0.94	-1.01	-0.92	-1.01	-1.13	-1.04	-1.00
	Y	0.06	0.10	0.05	0.07	0.14	0.04	0.08
	Z	-4.51	-4.47	-4.48	-4.48	-4.44	-4.47	-4.49
RT PUBIC TUBEROSITY	X	0.35	-0.03	0.26	0.36	0.45	0.17	0.31
	Y	-2.29	-2.25	-2.26	-2.28	-2.27	-2.27	-2.26
	Z	-6.16	-6.13	-6.12	-6.14	-6.12	-6.14	-6.17
LT PUBIC TUBEROSITY	X	0.36	-0.04	0.31	0.23	0.11	-0.27	0.14
	Y	2.79	2.79	2.79	2.77	2.78	2.84	2.86
	Z	-6.00	-6.00	-5.98	-5.98	-5.95	-5.92	-5.99
MEDIAL TROCHANTER	X	-8.61	-8.34	-6.62	-6.05	-5.84	-6.20	-6.18
	Y	-13.41	-13.37	-14.37	-14.23	-13.84	-14.29	-14.04
	Z	-5.31	-4.86	-5.46	-5.30	-4.94	-6.11	-6.30
LATERAL TROCHANTER	X	-10.10	-9.40	-7.38	-6.92	-6.55	-7.26	-6.80
	Y	-13.82	-13.84	-15.18	-15.11	-14.66	-15.08	-14.78
	Z	-4.70	-4.44	-5.27	-5.23	-5.11	-6.56	-6.95
SUPERIOR TROCHANTER (TROCHANTERION)	X	-9.26	-9.19	-8.37	-7.62	-8.02	-8.72	-8.50
	Y	-12.46	-12.36	-13.76	-13.65	-13.18	-13.70	-13.44
	Z	-3.16	-2.92	-3.72	-3.88	-4.05	-5.49	-6.10

TABLE 8 (con't)

SUBJECT 07

FLEXION (con't)
(of right leg)

		0°	10°	20°	30°	45°	60°	70°
SUP. NAIL HEAD	X	-6.56	-6.35	-5.15	-5.05	-4.95	-5.28	-5.44
	Y	-11.38	-11.12	-11.43	-11.31	-10.86	-11.47	-11.26
	Z	-5.34	-4.81	-5.09	-4.84	-4.34	-4.87	-4.89
SUP. NAIL POINT	X	-6.21	-6.60	-5.60	-5.25	-4.92	-5.28	-5.39
	Y	-10.20	-9.96	-10.28	-10.17	-9.80	-10.28	-10.09
	Z	-5.65	-5.13	-5.48	-5.31	-4.94	-5.24	-5.20
INF. NAIL HEAD	X	-5.60	-6.05	-4.73	-4.32	-4.39	-4.45	-4.37
	Y	-10.30	-10.05	-10.19	-10.05	-9.72	-10.22	-9.95
	Z	-6.39	-5.77	-6.01	-5.70	-5.03	-5.18	-5.06
INF. NAIL POINT	X	-6.65	-6.85	-5.97	-5.63	-5.52	-5.65	-5.25
	Y	-9.58	-9.36	-9.85	-9.73	-9.42	-9.83	-9.55
	Z	-5.73	-5.32	-5.77	-5.63	-5.32	-5.62	-5.65
RT PSIS	X	-14.36	-14.01	-14.77	-14.17	-13.75	-14.77	-14.29
	Y	-4.14	-3.30	-4.09	-3.85	-3.05	-4.23	-3.64
	Z	4.84	5.58	4.81	4.94	5.10	5.12	4.77
LT PSIS	X	-14.30	-14.32	-14.72	-14.53	-14.32	-14.57	-14.90
	Y	4.14	5.00	4.29	4.51	5.32	4.12	4.76
	Z	4.46	5.33	4.47	4.70	4.91	4.76	4.61
L5 DORSAL SPINE	X	-12.27	-12.33	-12.74	-12.59	-12.43	-12.6	-12.75
	Y	-0.40	0.34	-0.31	-0.12	0.59	-0.47	0.06
	Z	7.27	8.08	7.32	7.50	7.73	7.57	7.39
S1 DORSAL SPINE	X	-13.64	-13.51	-14.12	-13.87	-13.42	-13.88	-14.14
	Y	-0.30	0.53	-0.18	0.05	0.83	-0.34	0.23
	Z	5.39	6.18	5.39	5.59	5.78	5.66	5.51

TABLE 8 (con't)

SUBJECT 07

ROTATION (of right leg)		LATERAL ROTATION							
		0°	5°	10°	15°	20°	30°	35°	45°
RT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	-12.89	-13.12	-13.03	-13.01	-12.92	-13.12	-12.89	-12.85
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LT ASIS	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	13.23	13.13	13.16	13.19	13.22	13.15	13.12	13.22
	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYMPHYSION	X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-5.31	-5.32	-5.32	-5.32	-5.36	-5.33	-5.30	-5.27
SUPERIOR SYMPHYSION	X	-1.17	-1.06	-1.03	-1.04	-0.99	-1.04	-0.90	-1.04
	Y	0.08	0.02	0.08	0.12	0.07	0.04	0.06	0.10
	Z	-4.47	-4.48	-4.48	-4.48	-4.50	-4.49	-4.48	-4.44
RT PUBIC TUBEROSITY	X	0.02	0.26	0.31	0.13	0.22	0.28	0.21	0.21
	Y	-2.28	-2.28	-2.24	-2.24	-2.30	-2.25	-2.26	-2.28
	Z	-6.12	-6.16	-6.15	-6.14	-6.17	-6.16	-6.11	-6.10
LT PUBIC TUBEROSITY	X	-0.01	0.08	0.19	-0.19	0.12	0.18	0.18	0.10
	Y	2.80	2.80	2.86	2.86	2.80	2.84	2.77	2.78
	Z	-5.96	-5.97	-5.98	-5.95	-6.01	-5.98	-5.95	-5.93
MEDIAL TROCHANTER	X	-5.20	-6.86	-7.54	-8.38	-9.00	-9.57	-8.78	-9.50
	Y	-13.96	-14.61	-14.23	-13.87	-13.34	-13.97	-13.30	-12.95
	Z	-5.84	-5.59	-5.32	-5.13	-4.57	-4.86	-4.91	-4.72
LATERAL TROCHANTER	X	-5.81	-7.65	-8.53	-9.41	-9.79	-10.35	-10.05	-10.44
	Y	-14.99	-15.55	-14.94	-14.46	-13.71	-14.38	-13.70	-13.23
	Z	-5.42	-5.10	-4.77	-4.57	-4.01	-4.33	-4.33	-4.17
SUPERIOR TROCHANTER (TROCHANTERION)	X	-6.03	-7.52	-8.17	-9.17	-9.38	-9.90	-9.34	-9.62
	Y	-13.72	-14.13	-13.50	-13.02	-12.28	-12.94	-12.27	-11.81
	Z	-3.68	-3.42	-3.17	-2.98	-2.52	-2.76	-2.81	-2.71

TABLE 8 (con't)

SUBJECT 07

ROTATION (con't)
(of right leg)

		LATERAL ROTATION							
		0°	5°	10°	15°	20°	30°	35°	45°
SUP. NAIL HEAD	X	-4.69	-5.44	-6.02	-6.44	-6.50	-6.84	-6.38	-6.75
	Y	-10.87	-11.50	-11.44	-11.34	-11.10	-11.61	-11.19	-10.94
	Z	-5.57	-5.47	-5.29	-5.21	-4.90	-5.11	-5.12	-5.00
SUP. NAIL POINT	X	-5.33	-5.87	-6.17	-6.91	-6.76	-6.98	-6.53	-6.88
	Y	-9.85	-10.35	-10.21	-10.18	-9.98	-10.46	-10.06	-9.81
	Z	-5.74	-5.69	-5.57	-5.47	-5.21	-5.42	-5.44	-5.31
INF. NAIL HEAD	X	-4.90	-5.31	-5.71	-6.30	-5.88	-6.47	-5.97	-6.45
	Y	-9.58	-10.15	-10.15	-10.23	-10.07	-10.59	-10.20	-10.01
	Z	-6.45	-6.42	-6.31	-6.21	-6.01	-6.14	-6.14	-6.01
INF. NAIL POINT	X	-6.03	-6.34	-6.79	-7.14	-6.92	-7.40	-6.71	-6.86
	Y	-9.49	-9.91	-9.72	-9.62	-9.37	-9.88	-9.43	-9.19
	Z	-5.77	-5.77	-5.64	-5.60	-5.37	-5.53	-5.57	-5.46
RT PSIS	X	-14.76	-14.74	-14.49	-14.76	-14.39	-14.60	-14.39	-14.41
	Y	-3.41	-4.44	-3.96	-3.77	-3.46	-4.47	-3.79	-3.22
	Z	5.00	5.00	4.95	4.99	5.38	5.01	4.87	5.00
LT PSIS	X	-14.71	-14.95	-14.78	-14.91	-14.55	-14.80	-14.70	-14.94
	Y	4.92	3.98	4.39	4.60	4.91	3.96	4.52	5.13
	Z	4.69	4.73	4.71	4.67	5.10	4.73	4.64	4.82
L5 DORSAL SPINE	X	-12.70	-13.19	-12.99	-13.09	-12.43	-12.85	-12.74	-12.94
	Y	0.26	-0.63	-0.24	-0.06	0.25	-0.63	-0.08	0.44
	Z	7.50	7.62	7.56	7.56	7.85	7.58	7.42	7.59
S1 DORSAL SPINE	X	-14.15	-14.15	-14.07	-14.16	-13.62	-14.07	-13.80	-14.19
	Y	0.44	-0.48	-0.10	0.13	0.41	-0.52	0.07	0.63
	Z	5.61	5.60	5.60	5.58	5.92	5.64	5.47	5.70

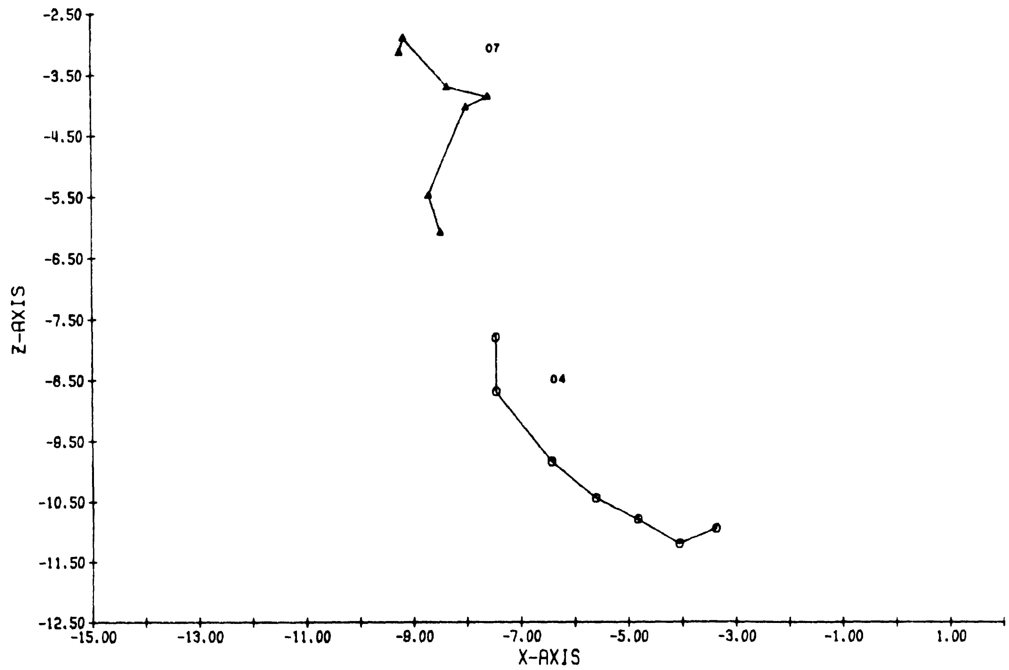


Figure 7. Path of Trochanterion relative to pelvic axis system during hip flexion in the sagittal plane for subjects 04 and 07.

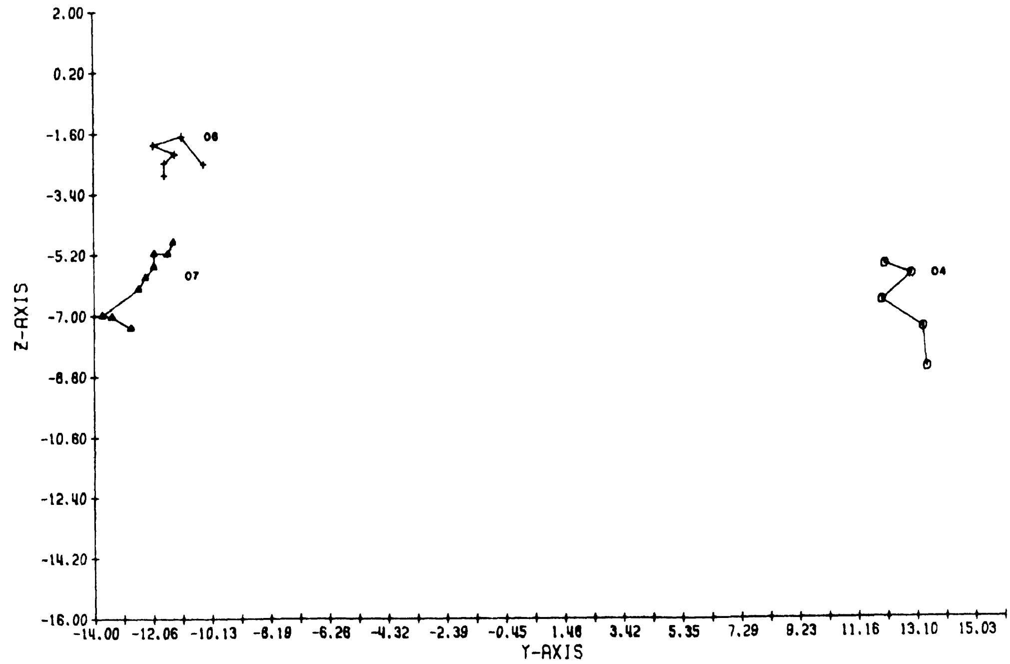


Figure 8. Path of Trochanterion relative to pelvic axis system during hip abduction in the frontal plane for subjects 04, 06 and 07.

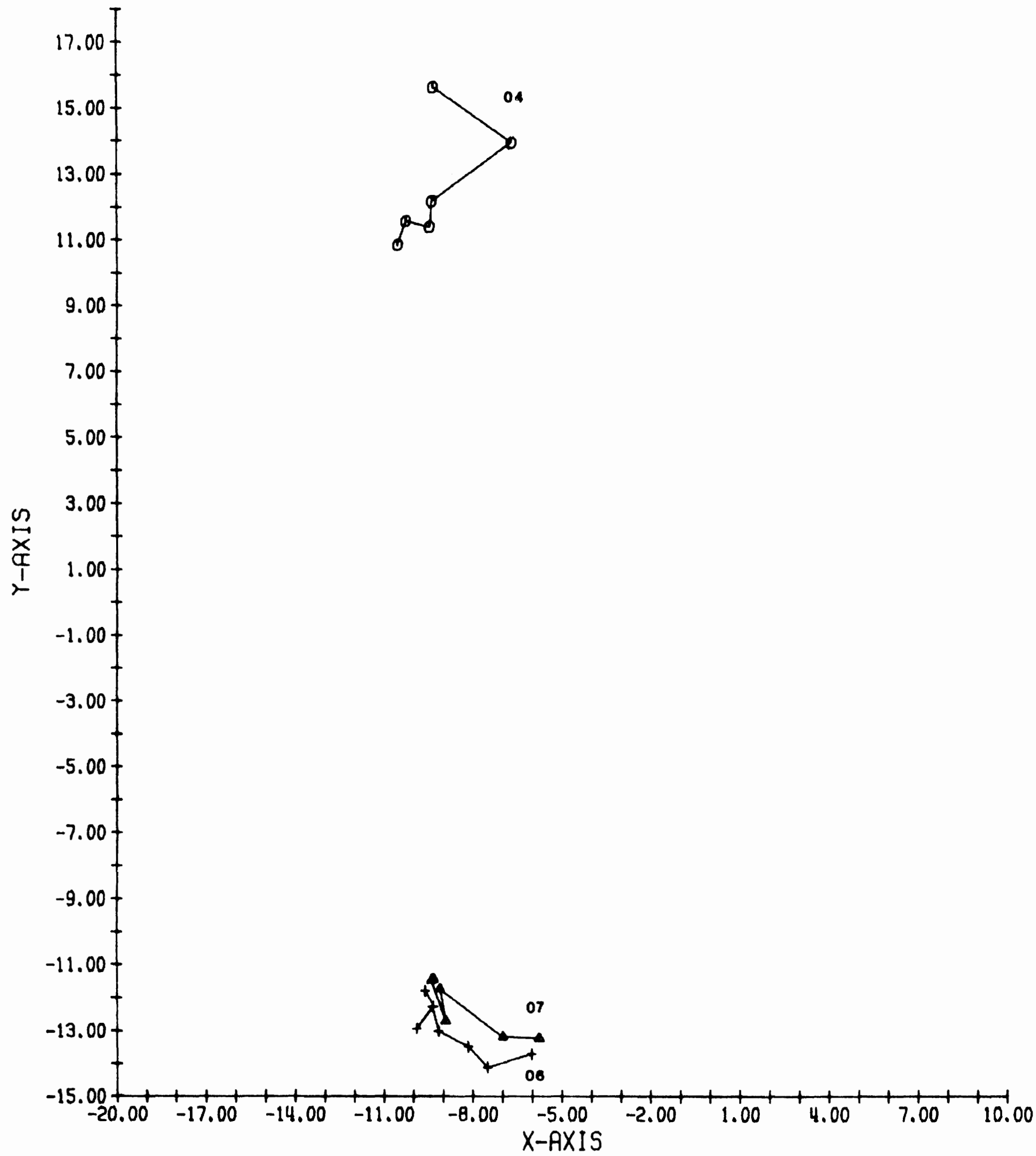


Figure 9. Path of Trochanterion relative to pelvic axis system during hip rotation in the transverse plane for subjects 04, 06 and 07.

a

b

c

d

Figure 10a-n. Sequential photographs of every fifth frame from a cineradiographic film of hip abduction for subject 07.

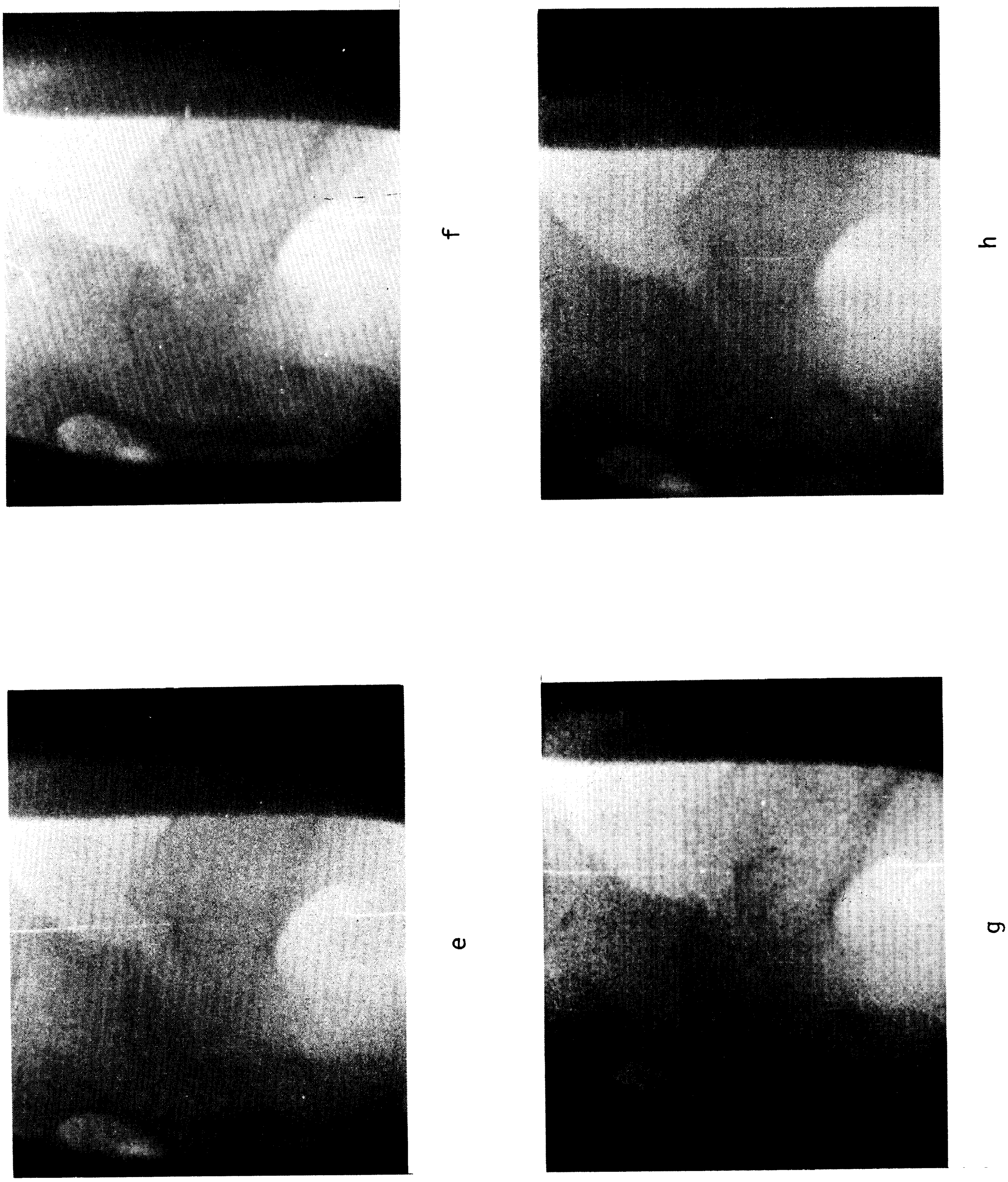


Figure 10 (continued)

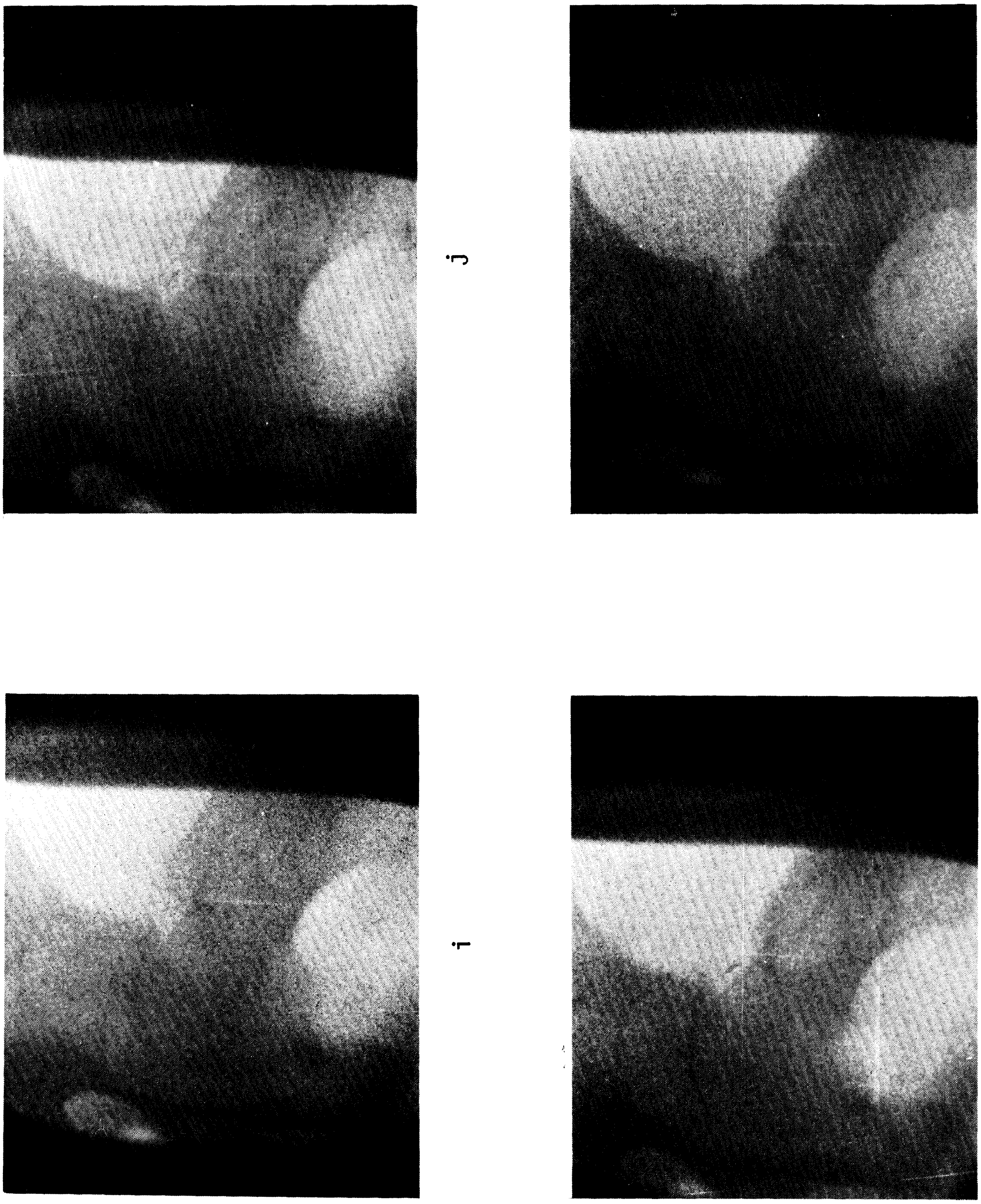
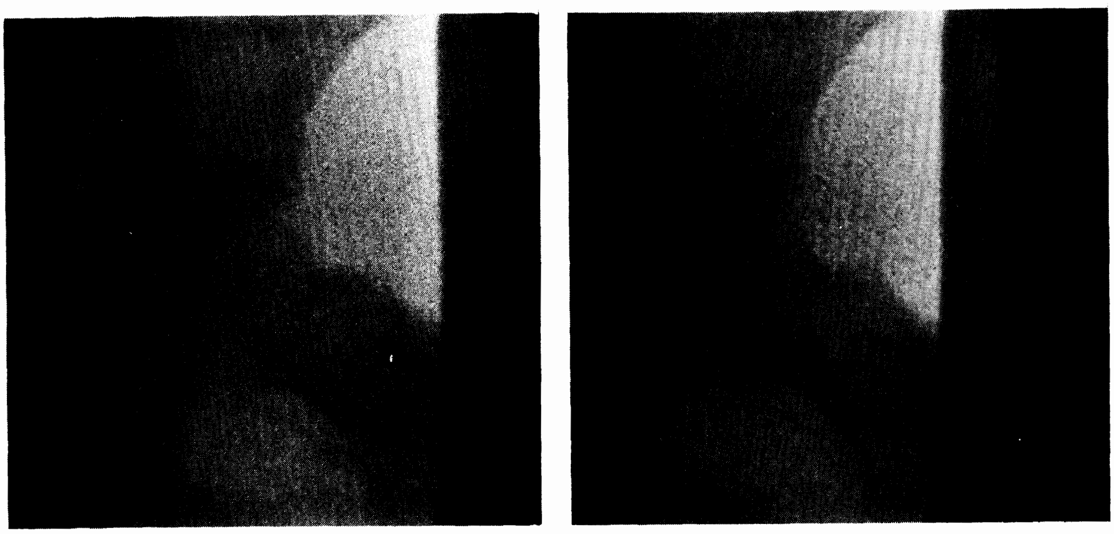


Figure 10 (continued)

is needed. The translatory motion of the femur may be large enough so that it must be accounted for in measurements to provide a satisfactory basis for predictive modeling of hip joint motion. This will be a particularly important parameter for simulations of high acceleration environments where segment "stops" are more a result of environmental geometry than biological function.



m n

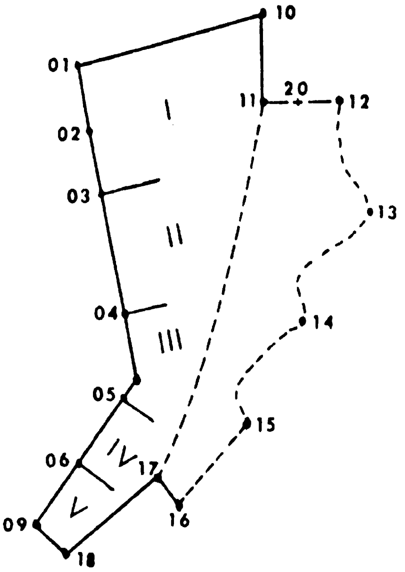
Figure 10 (continued)

3.2 Investigations involving skeletal material at CAMI.

3.2.1 Skeletal variation in anatomical landmark location.

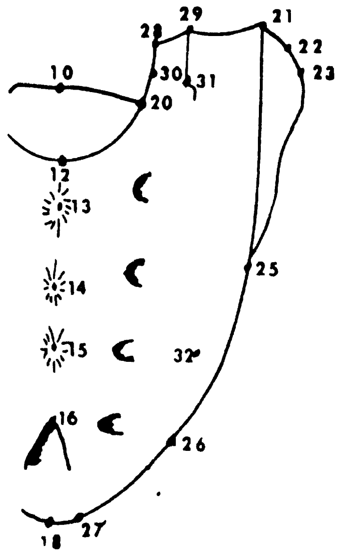
The data obtained from osteological measurements at CAMI are primarily related to questions concerning "stability" of landmarks and the use of anatomical landmarks for axis system definition. Schematic drawings of the landmarks on the sacrum (Figures 11-14) and innominate (Figures 15-21) bones illustrate the total spectrum of landmarks whose three-dimensional coordinate location is measured. Only a small number of these landmarks will be utilized by Systems Anthropometry since many of them do not meet the requirements of body surface palpability and possibly do not represent functional biological features. However, all of these landmarks are needed to provide a geometric description of the shape of the pelvis for manikin design while the limited number reported upon in this section will probably be sufficient to describe the position and size of the pelvis for computer simulations.

The pelvic landmarks which define the axis system for this investigation are, as in the HSRI cadaver data, the right and left anterior superior iliac spines (ASIS) and symphysion. The data presented in Table 9 and plotted in Figures 22 and 23 have been located relative to a coordinate system based on these three landmarks. These landmarks used to define the secondary axis system are palpable on the surface of the body, but the degree to which they can be accurately located remains as an unanswered question. Symphysion is not a skeletal point since it lies on the superior edge of the pubic symphysis (a cartilagenous plate). Thus, another landmark might be identified which is a palpable skeletal feature, maintains geometric stability, and can be accurately defined within the context of biological function and population variability.



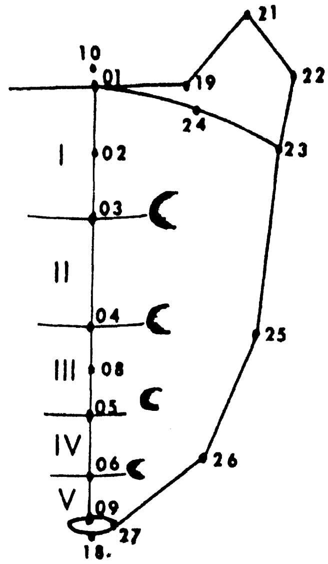
01	Promontorion
02	S1 Center
03-06	Segment Union Points
09	Caudion, Anterior
10	1st Sacral Body, Posterior
11	Sacral Canal, Supero-anterior Floor
12	Sacral Canal, Anterior Roof
13	Sacral Spine, S1
14	Sacral Spine, S2
15	Sacral Spine, S3
16	Sacral Canal, Posterior Roof
17	Sacral Canal, Infero-anterior Floor
18	Caudion, Posterior
19	Sacral Canal, Wall

Figure 11 Projected schematic of sacrum showing midline landmarks.



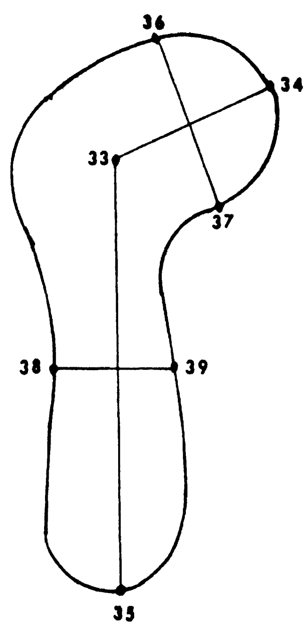
10	1st Sacral Body, Posterior
12	Sacral Canal, Anterior Roof
13	Sacral Spine, S1
14	Sacral Spine, S2
15	Sacral Spine, S3
16	Sacral Canal, Posterior Roof
18	Caudion, Posterior
20	Sacral Canal, Wall
21	Posterior Alar-Auricular Point
22	Lateral Alar-Auricular Point
23	Anterior Alar-Auricular Point
25	Inferior Sacro-Iliac Junction
26	Inferior Sacral Angle
27	Caudion, Lateral
28-31	Superior Auricular Facet
32	Posterior Sacral Tubercle

Figure 12 Posterior view of sacrum showing midline and lateral landmarks.



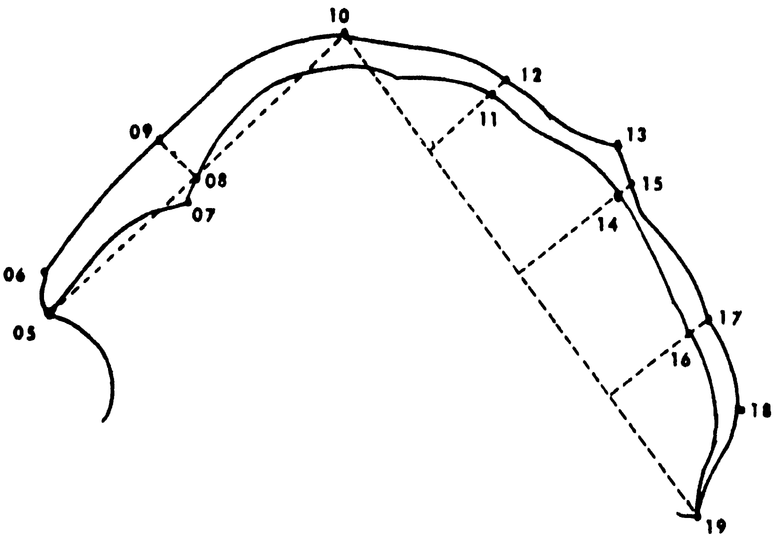
01 Promontorion
02 S1 Center
03-07 Segment Union Points
09 Caudion, Anterior
10 1st Sacral Body, Posterior
18 Caudion, Posterior
19 1st Sacral Body, Lateral
21 Posterior Alar-Auricular Point
22 Lateral Alar-Auricular Point
23 Anterior Alar-Auricular Point
24 Mid-Alar-Auricular Point
25 Inferior Sacro-Iliac Junction
26 Inferior Sacral Angle
27 Caudion, Lateral

Figure 13 Anterior view of sacrum showing midline and lateral landmarks.



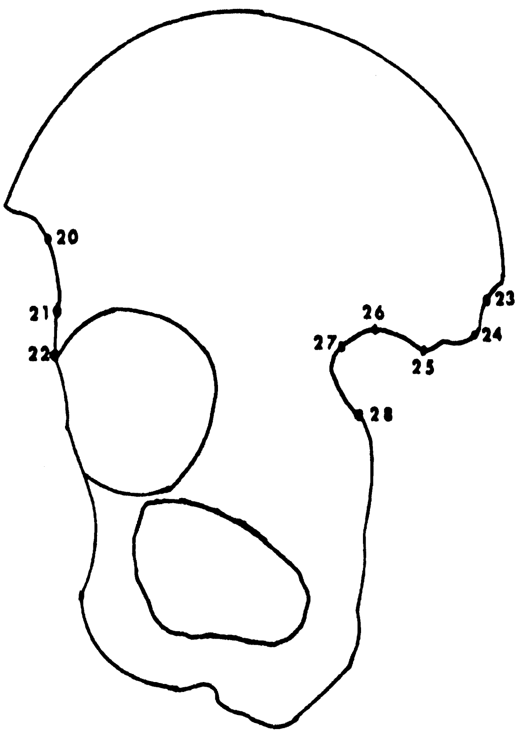
33 Sacro-Iliac Midpoint
34 Superior Pole
35 Inferior Pole
36 Superior Lobe, Superior Margin Midpoint
37 Superior Lobe, Inferior Margin Midpoint
38 Inferior Lobe, Anterior Margin
39 Inferior Lobe, Posterior Margin

Figure 14 Schematic view of sacro-iliac joint surface showing landmarks.



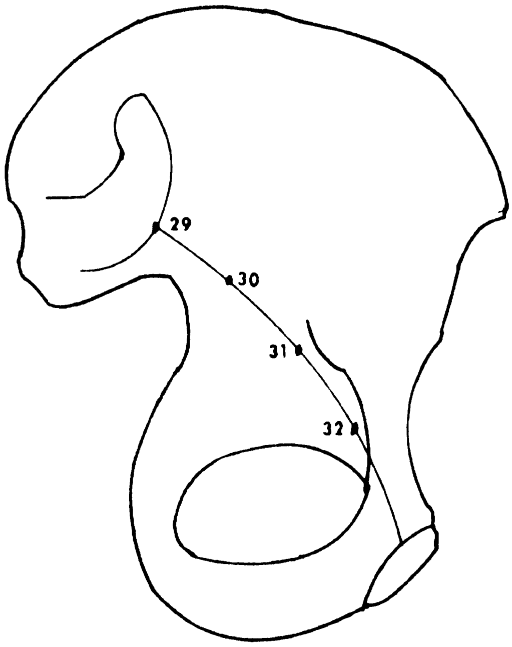
05 Iliospinale, Antero-superior
06 Iliospinale, Crest
07 Iliocristale, Antero-lateral
08 Anterior Segment Midpoint, Lateral
09 Anterior Segment Midpoint, Medial
10 Iliocristale, Summum
11 Posterior Segment Point, Anterior Lateral (1st)
12 Posterior Segment POint, Anterior Medial (1st)
13 Iliocristale, Postero-medial
14 Posterior Segment Point, Intermediate Lateral (2nd)
15 Posterior Segment Point, Intermediate Medial (2nd)
16 Posterior Segment Point, Posterior Lateral (3rd)
17 Posterior Segment Point, Posterior Medial (3rd)
18 Iliocristale, Posterior
19 Iliospinale, Postero-superior

Figure 15 Lateral view of iliac crest showing landmarks.



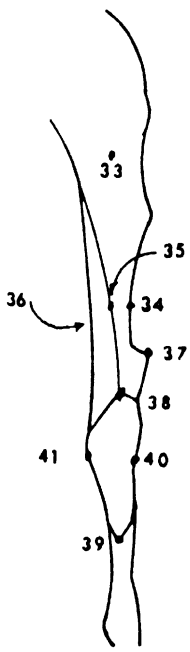
20 Anterior Iliac Notch Point
21 Iliospinale, Antero-Inferior
22 Anterior Iliac Base Point
23 Posterior Iliac Notch Point
24 Iliospinale, Postero-inferior
25 Bouisson Tubercle
26 Superior Sciatic Notch Point
27 Apex of Sciatic Notch
28 Anterior Sciatic Notch Point

Figure 16 Lateral view of innominate showing anterior and posterior iliac border landmarks.



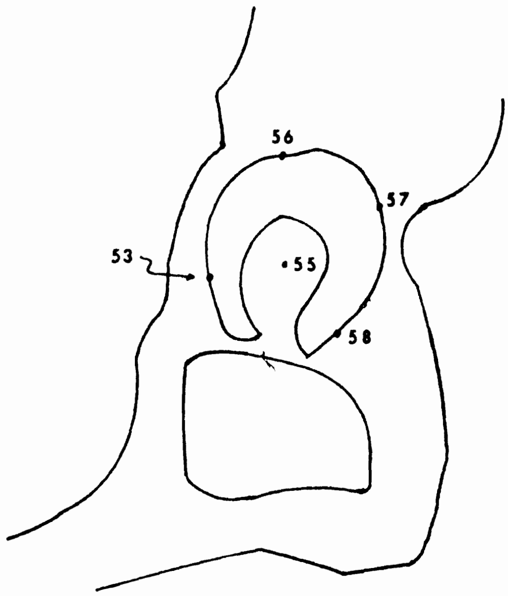
29 Anterior Auricular Point
30 Posterior Inlet Point
31 Intermediate Inlet Point
32 Anterior Inlet Point

Figure 17 Medial view of innominate showing pelvic inlet landmarks.



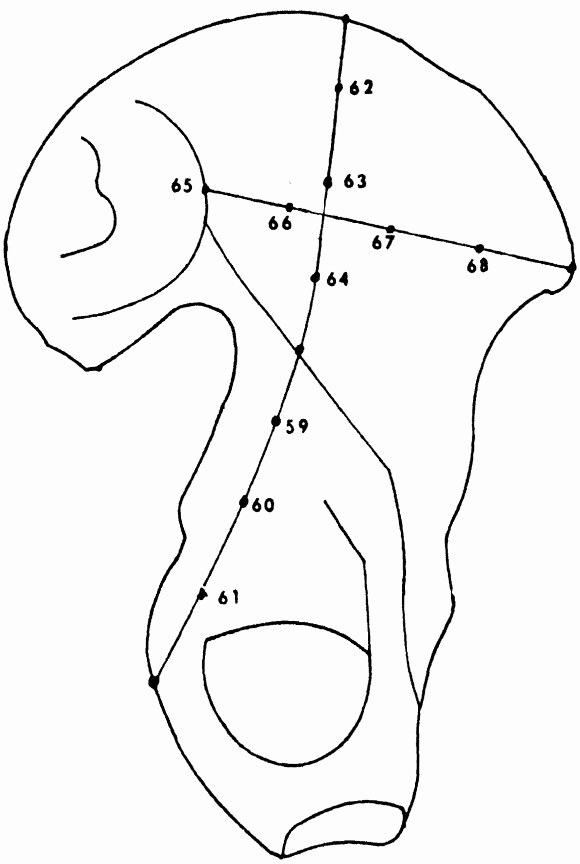
33 Pubic Eminence Point
34 Anterior Pubic Ramus Point
35 Superior Pubic Ramus Point
36 Inferior Pubic Ramus Point
37 Pubotubercle
38 Superior Symphyseal Pole
39 Inferior Symphyseal Pole
40 Anterior Symphyseal Point
41 Posterior Symphyseal Point

Figure 18 Medial view of pubis showing landmarks.



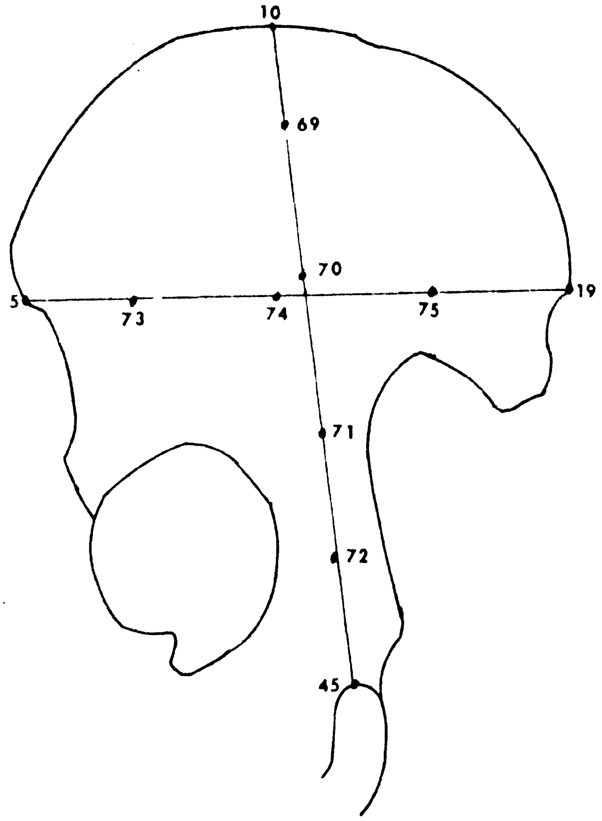
53	Acetabulum, Anterior
54	H-Point (Not shown)
55	Acetabular Center Point
56	Acetabulum, Superior
57	Acetabulum, Posterior
58	Acetabulum, Inferior

Figure 19 Lateral view of acetabulum showing landmarks.



59	Superior Ischial Inner Surface Point
60	Intermediate Ischial Inner Surface Point
61	Inferior Ischial Inner Surface Point
62	Superior Vertical Iliac Fossa Contour Point
63	Intermediate Vertical Iliac Fossa Contour Point
64	Inferior Vertial Iliac Fossa Contour Point
65	Lateral Auricular Point
66	Posterior Transverse Iliac Fossa Contour Point
67	Intermediate Transvers Iliac Fossa Contour Point
68	Anterior Transverse Iliac Fossa Contour Point

Figure 20 Medial view of Innominate showing surface contour landmarks.



05	Segment Union Point
10	1st Sacral Body, Posterior
19	1st Sacral Body, Lateral
45	Superior Tuberosity Point
69	Superior-most Vertical Lateral Ischio-Iliac Contour Point
70	Superior-Intermediate Vertical Lateral Ischio-Iliac Contour Point
71	Inferior-Intermediate Vertical Lateral Ischio-Iliac Contour Point
72	Inferior-most Vertical Lateral Ischio-Iliac Contour Point
73	Anterior Transvers Lateral Iliac Surface Contour Point
74	Intermediate Transvers Lateral Iliac Surface Contour Point
75	Posterior Transvers Lateral Iliac Surface Contour Point

Figure 21 Lateral view of Innominate showing surface contour landmarks.

TABLE 9

Summary statistics of subset of
Hamann - Todd male 3-D pelvic data
(measurements in cm.)

VARIABLE		N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
RT ASIS	X	25	0.	0.	0.	
	Y	26	-13.22	-9.47	-11.46	.82
	Z	24	0.	0.	0.	
LT ASIS	X	26	0.	0.	0.	
	Y	26	9.31	13.74	11.57	.98
	Z	26	0.	0.	0.	
RT H-POINT	X	26	-5.79	-3.67	-4.74	.48
	Y	26	-9.27	-7.15	-8.35	.48
	Z	26	-8.04	-3.25	-6.43	1.10
LT H-POINT	X	26	-5.62	-3.61	-4.77	.46
	Y	26	7.00	9.48	8.57	.54
	Z	26	-7.73	-2.81	-6.35	1.11
RT ILIOCRISTALE, SUMMUM	X	26	-24.03	-1.76	-5.35	3.91
	Y	26	-14.28	-10.78	-12.37	.81
	Z	26	4.72	19.98	6.56	2.81
LT ILIOCRISTALE, SUMMUM	X	26	-6.44	-1.82	-4.59	.99
	Y	26	9.88	13.91	12.47	.82
	Z	26	5.15	7.74	6.34	.67
RT ISCHIALE	X	26	-11.20	-8.44	-9.66	.76
	Y	26	-7.29	-4.98	-6.01	.70
	Z	26	-13.96	-7.24	-11.62	1.56
LT ISCHIALE	X	26	-11.14	-8.45	-9.66	.60
	Y	26	4.95	7.40	6.13	.63
	Z	26	-13.93	-7.02	-11.52	1.55
LT PSIS	X	26	-15.02	-9.60	-13.01	1.17
	Y	26	2.29	4.58	3.49	.52
	Z	26	-1.36	6.19	1.39	1.47
PROMONTORION	X	26	-6.74	-3.89	-5.55	.70
	Y	26	-.99	.73	-.52	.48
	Z	26	-1.27	4.96	1.45	1.12
SYPHYSION	X	26	0.	0.	0.	
	Y	23	0.	0.	0.	
	Z	26	-9.79	-5.22	-7.64	1.12

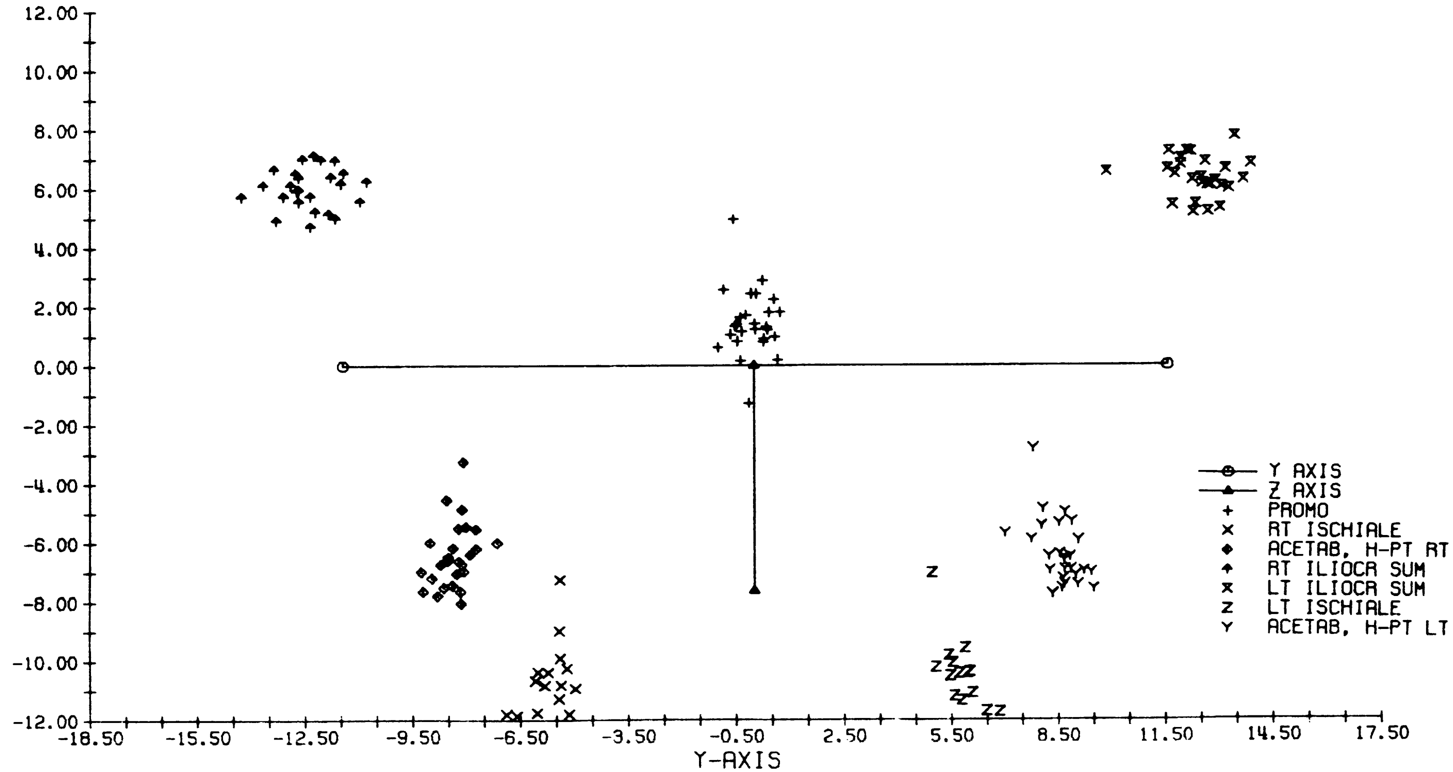


Figure 22 HAMANN-TODD MALE 3-D DATA PLOTTED RELATIVE TO SECONDARY AXIS SYSTEM IN THE FRONTAL PLANE UNITS = CM

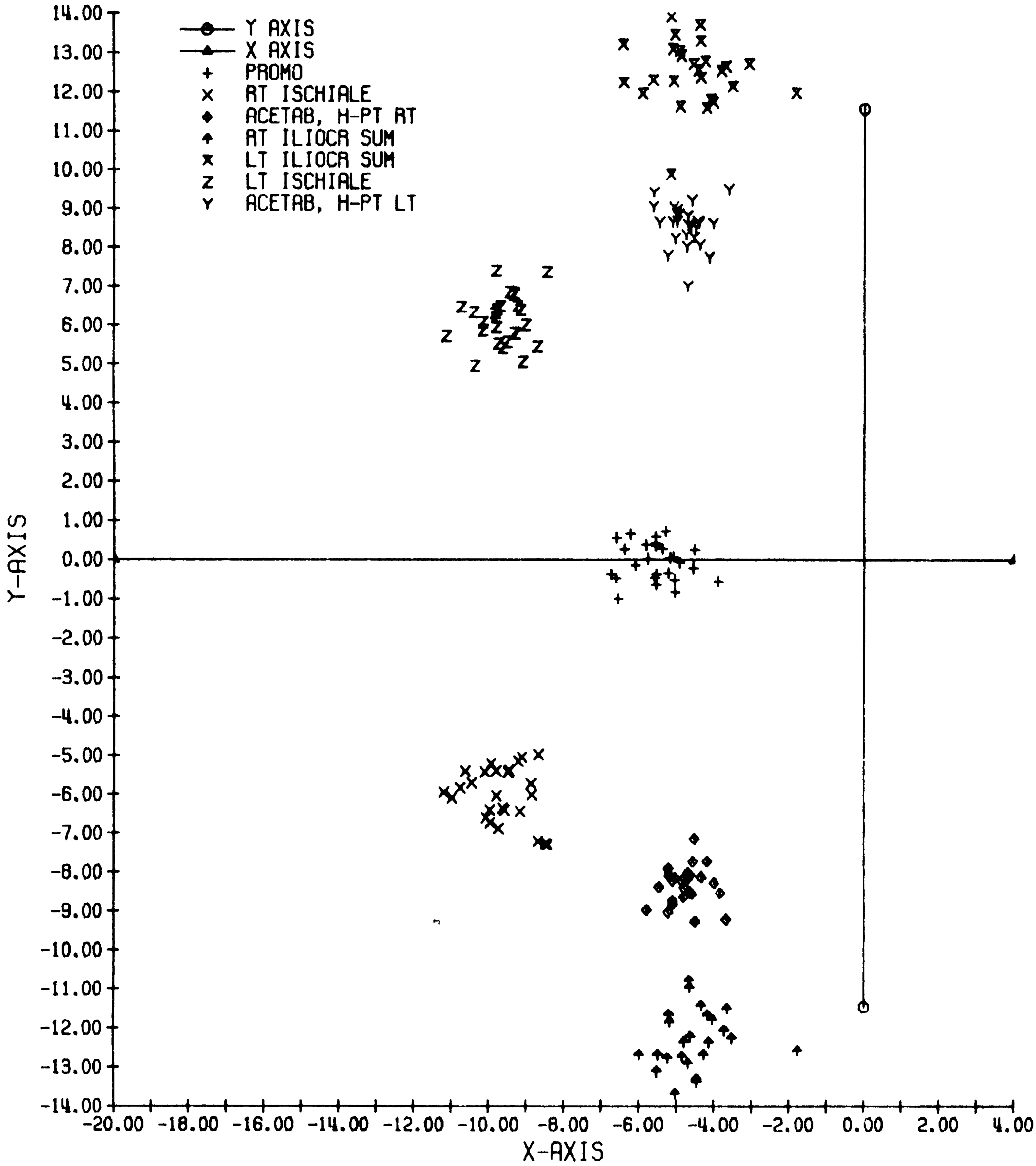


Figure 23 HAMANN-TODD MALE 3-D DATA PLOTTED RELATIVE TO SECONDARY AXIS SYSTEM IN THE TRANSVERSE PLANE UNITS = CM

4. SUMMARY AND RECOMMENDATIONS

Basic research in Systems Anthropometry has achieved progress in several areas and we can make several recommendations relative to instrumentation and research problems. This last section will summarize what Systems Anthropometry has accomplished and provide suggestions for future research.

4.1 Summary of Phase II research.

Research in Systems Anthropometry has been directed towards developing an experimental philosophy, data analysis methodology, and collecting data. This effort has not, therefore, included the development of new equipment or techniques when it was possible to utilize existing technical capabilities. As a result, our most significant results have been obtained in laying the philosophical foundation for Systems Anthropometry. The following list briefly describes each of the major components in this experimental philosophy.

1) Biological variability must be considered as a set of probabilistic phenomena in deterministic models. That is, the length of an anatomical "link" is defined by two probabilistic sets of parameters: a) the probable size configuration of a skeleton in an individual in the population, and b) the probable location of adjacent joint centers of mobility. Thus, the possible lengths of a bone separating adjacent anatomical joints are distributed in the population. The same phenomenon of biological variability is also true for joint centers of mobility. Thus, the concept of a fixed-length "link" must be modified to accept additional probabilistic parameters.

2) Body position and mobility must be considered simultaneously in three-dimensional space since extrinsic and intrinsic geometries affect body mobility. That is, the position of the body relative to an environmental workspace as well as the relative three-dimensional location of each body segment will

determine the extent of body mobility within the total globographic range. Thus, the traditionally independent concepts of body position and body mobility must be considered together.

3) The data collection and data analysis methodologies must incorporate the use of anatomical frames of reference defined by functionally significant landmarks. The use of anatomically-based Cartesian coordinate axes systems provides comparability between subjects and provides a possible means by which joint mobility becomes predictable. Other spatial characteristics of a segment, such as its inertial properties must be referenced to the anatomical frames of reference.

4) Functional and stable landmarks must be defined in skeletal geometry. Skeletal features provide the best anatomical landmarks for kinematical research problems since soft tissue features are mobile relative to each other. Thus, the skeleton provides the only rigid, relatively fixed landmarks suitable for axis system definition and motion tracking to define body position and mobility.

The following list describes briefly each of the major components of methodology.

1) An anatomically-based Cartesian coordinate axis system can be defined relative to three non-colinear skeletal landmarks on a rigid bone in the skeleton. The three landmarks define a plane from which a normal is constructed which serves to define two additional planes.

2) To describe body position and mobility, three types of axes systems are necessary. The first is an inertial frame of reference that does not move and is independent of the human body. The second axis system is a whole-body frame of reference which corresponds approximately to the traditional anatomical reference system and is located in the pelvis. When the location of this axis system is specified, the general orientation of the body

relative to the inertial frame of reference is described. The third type of axis system is a body segment frame of reference which is unique to a specific segment. These axes systems define the location and orientation of the mass distribution properties of each segment as well as the kinematic parameters. Thus, the body is viewed as a system of segments each of which move relative to each other.

3) Body mobility is defined kinematically by a three-dimensional motion analysis which describes one axis system moving relative to another axis system. The three-dimensional analysis requires six parameters in order to solve the equations describing the kinematically complete six degrees of freedom. The analytical procedures have been demonstrated in Kinzel, Hall, and Hillbery (1972). The results from this analysis will provide mathematically complete descriptions of segment mobility but the applicability of these results to statistical analysis is unknown.

4) Skeletal landmarks measured in three-dimensional Cartesian coordinates may be described in a sample through the use of probability ellipsoids. Thus, the statistical summarization of the data on 280 individuals in Section 4.5 of the Interim Report can also be utilized in the three-dimensional description of body position. It is anticipated that similar techniques will be used on the resultant body mobility data.

5) Targets on the body surface and on skeletal features can be measured accurately with the stereo-radiographic technique. The relationship between internal and external landmarks may be measured as well as the motion of an incrementally-moved axis system defined by three landmarks. The description of axis system motion through the use of incremental stereo-radiographs relies upon relatively low data density along the path of motion. Other techniques might resolve the incremental displacement into finer units of motion.

A small amount of data have been collected in Phase II. The following list briefly describes the results.

1) The spatial relationship between the internal and external landmarks in the lumbar/pelvic/femur region of the body has been investigated in two fresh cadavers. The results are geometrically defined relative to the secondary axis system in the pelvis. Additional research is needed to expand the sample size for statistical analysis of this relationship.

2) The motion of the femur relative to a fixed pelvic axis system was investigated in three fresh cadavers. The three-dimensional Cartesian coordinates for each measured landmark were examined using two-dimensional graphical techniques. The data are currently being studied using three-dimensional analytical techniques.

3) Densitometric measurements of skeletal muscle have been made on specimens from six fresh cadavers. The sample for these data will be expanded during Phase III. Results of this effort will be used in a geometric model of a body segment presented in the Interim Report. The model is also being revised to include a more sophisticated and complete treatment of the skeletal mass distribution of each segment.

4) The stability of skeletal features on the pelvis is being investigated on a collection of osteological specimens. The specimens are being measured in groups of approximately 30 males and 30 females until the total sample of approximately 150 males and 150 females is completed. Results, at this time, are preliminary. The statistical analysis of these data will utilize the techniques employed on the sample of 280 subjects investigated in Phase I.

4.2 Recommendations for Systems Anthropometry Research.

4.2.1 Instrumentation

There are two major concerns in taking the measurements required for Systems Anthropometry. First, to define a segment axis system from landmarks located as far apart as possible, a large stereo-measurement format is needed with a 36 cm width, 90 cm length, and a 60 cm depth. This fixed measurement space should have approximately 1% resolution with an accuracy of ±0.1 mm for the complete stereo-radiographic system to assure useably accurate data for axes systems definitions. Given an experimental system of this caliber,* the investigation would be able to focus on the biological variability of the population and the ability of the observer to record this variability.

In order to accomplish this level of measurement capability the following is recommended:

1) assured orthogonality of x-ray stereo base, fiducial plane, and film plane by accurate alignment techniques with an x-ray system dedicated solely for systems anthropometric research;

2) digital encoding methods for referencing repositioning of x-ray head and fiducial plane;

3) making the film plane independent of the fiducial plane, but orthogonal to the stereo base;

4) upon completion of a dedicated x-ray facility, a comprehensive calibration study which isolates and minimizes systematic and random error, and

5) application of these experimentally determined correction factors for systematic error to the measurement data in the computer program.

*A facility that will meet these requirements is currently being constructed at Michigan State University, College of Osteopathic Medicine where the project is now continuing in Phase III.

The second major concern in the measurements necessary for systems anthropometry concerns the measurement of the kinematic properties of each joint, or relative segment motion. This measurement must be made for small increments of joint displacement. Rotatory and translatory motions must be measured to obtain enough parameters to describe the characteristics of each relative to six degrees of freedom. The need for highly accurate information is also important since small increments of motion in the joint produces relatively large increments of motion at the extremity. There are two measurement techniques available to obtain the high resolution and high accuracy of small rotatory and translatory displacement in the anatomical joint--digital stereo-radiography and linkage transducers. Stereo-radiography has been used throughout this program and is familiar to all concerned. The linkage transducer is an assembly of links and revolute joints, and the ends of this transducer can be attached to two bodies. The transducer continuously measures the six degrees of freedom of relative motion of these bodies without restricting that motion. From these records of relative position, the kinematic characteristics of the joint(s) between the segments to which the linkage transducer is attached can be determined. By continuously measuring the six degrees of freedom of general three-dimensional motion with this type of instrument, the relative velocity and acceleration of segments to which it is attached can also be determined as continuous functions of time.

The best approach probably lies in a combination of both systems in order to use the advantages unique to both systems, and to answer questions relative to the three-dimensional anthropometric description of the dynamic body. Stereo-radiography could be used for measuring an initial position of skeletal segments and linkage transducer relative to each other. The relative movement of the segments could then be measured with the linkage transducer. The positions of the segments relative to each other and the linkage transducer would be checked with stereo-radiographs.

4.2.2 Future Research

The research questions posed for Systems Anthropometry are primarily directed towards an understanding and documentation of the variability of body position and mobility. Body mobility must be investigated for both intra- and inter- individual variability. Of primary concern is the degree to which the joint kinematics are controlled by deterministic phenomenon versus probabilistic phenomenon. This question must be investigated by intensively studying reproducibility of the kinematic description on single joints of individuals. Following this type of research activity, the range and amount of variation in the population can be investigated. To obtain a thorough understanding of the measurable parameters of joint mobility in the population sufficient for prediction of body position and mobility, measurements with accuracy as good or better than the present work at HSRI must be continued to other body regions. These results will be analyzed using a recently developed three-dimensional kinematic analysis for a complete description of three-dimensional motion. The data and analytical results must be presented in explicit mathematical functions and in understandable computer aided graphic displays.

This investigation should therefore continue into collecting and analyzing additional data on the hip joint. Additional research should be directed towards a similar investigation of the spinal column. Both of these research areas should include parameters of body size in their investigation in order to examine the relationship between body size and kinematics. In conclusion, the primary goal for systems anthropometry is to provide a biological basis for a mechanical model to be used in computer simulations and minikin design.

5. LIST OF REFERENCES

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6. APPENDIX

A. Cadaver Anthropometry

A.1. List of Landmark Definitions

ACROMION The most lateral projection of the acromial process of the scapula.

ANTERIOR SUPERIOR ILIAC SPINE A point on the pelvis located at the most anterior projection of the superior spine on the iliac portion of the pelvis.

BALL OF HUMERUS The level of the most superior portion of the bicipital groove lying between the greater and lesser tuberosities of the humerus.

CRINION The midpoint of the hairline on the forehead.

DACTYLION The most distal point on the tip of the middle digit (III).

DISTAL Remote; farther from any point of reference; opposed to proximal.

FIBULARE The most proximal point on the head of the fibula.

GLABELLA The most anterior point on the forehead that lies between the brow ridges in the mid-sagittal plane.

GONION The most lateral point at the intersection of the horizontal and ascending rami of the mandible.

ILIOCRISTALE The most superior point on the lateral edge of the iliac crest of the pelvis.

MALLEOLUS The most medial and lateral projections on the distal end of the tibia and fibula, respectively.

MANUBRIUM The cranial portion of the sternum, which articulates with the clavicles and the first two pairs of ribs.

MASTOID The most inferior point on the tip of the mastoid process of the skull.

MENTON The most antero-inferior point on the chin in the mid-sagittal plane.

METACARPALS The long bones in the palm of the hand which articulate with the phalanges of the fingers.

NUCHALE The point on the back of the skull in the mid-sagittal plane defined by the superior margin of the occiput and the neck, or nuchal, musculature.

OLECRANON PROCESS The proximal portion of the ulna which forms the bony projection in the posterior projection of the elbow.

OPISTHOCRANION The point on the back of the skull which lies at the greatest distance from Glabella.

PROXIMAL Nearest; closer to any point of reference; opposed to distal.

RADIALE The most superior lateral projection of the head of the radius found superficially at the level of the elbow dimple.

SPHYRION The most distal tip of the tibia on the medial side of the ankle.

STYLION The most distal tip of the radial styloid process.

SUBSTERNALE A point on the anterior surface of the chest at the most inferior tip of the xiphoid process of the sternum.

SUPRASTERNALE A point on the most inferior margin of the sternal notch at the top of the manubrium.

SYMPHYSION A point in the mid-sagittal plane on the most anterior superior edge of the pubic symphysis of the pelvis.

TIBIALE The point on the proximal end of the tibia located as the highest point on the margin of the glenoid in an antero-medial direction near the knee joint.

TRAGION The notch in the cartilage of the ear at the superior margin of the tragus.

TROCHANTERION The most superior projection of the Greater Trochanter of the femur.

VERTEX The most superior point in the mid-sagittal plane on the head.

A.2. List of Measurement Definitions

1. Weight: Record the nude weight of the cadaver to the nearest tenth of a kilogram at time of measurement.
2. Stature: Lay the cadaver on the measuring table with head in the Frankfort Plane against a board tangent to Vertex and parallel to the Frankfort Plane. Measure with an anthropometer the perpendicular distance from the headboard to the most distal point on the heels of the feet and average for total stature. The measurement should be parallel to the long axis of the body.
3. Trochanterion Height: Measure with an anthropometer the perpendicular distance from the headboard to right Trochanterion. The measurement should be parallel to the long axis of the body.
4. Symphysion Height: Measure with an anthropometer the perpendicular distance from the headboard to Symphysion. The measurement should be parallel to the long axis of the body.
5. Anterior Superior Iliac Spine (ASIS) Height: Measure the perpendicular distance from the headboard to right Anterior Superior Iliac Spine. The measurement should be parallel to the long axis of the body.
6. Iliocristale Height: Measure the perpendicular distance from the headboard to right Iliocristale .

The measurement should be parallel to the long axis of the body

7. Substernale Height: Measure the perpendicular distance from the headboard to Substernale. The measurement should be parallel to the long axis of the body.

8. Mid-Chest Height: Measure the perpendicular distance with an anthropometer from the headboard to the point on the anterior surface of the chest mid-way between Suprasternale and Substernale. The measurement should be parallel to the long axis of the body.

10. Acrominon Height: Measure the perpendicular distance with an anthropometer from the headboard to right Acromion. The measurement should be parallel to the long axis of the body.

11. Mastoid Height: With the head in the Frankfort Plane against a board tangential to Vertex and parallel to the Frankfort Plane, measure the perpendicular distance from the headboard to the most inferior tip of the right mastoid process.

12. Tragion Height: With the head in the Frankfort Plane against a board tangential to Vertex and parallel to the Frankfort Plane, measure the perpendicular distance with an anthropometer from the headboard to right Tragion.

13. Tragion Depth: With the head in the Frankfort Plane, measure the perpendicular distance with an anthropometer from the surface on which the back of the head is resting to right Tragion.

14. Suprasternale Depth: Measure the perpendicular distance with an anthropometer from the surface on which

the body is resting to Suprasternale.

15. Mid-Chest Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to the point on the anterior surface of the chest mid-way between Suprasternale and Substernale.

16. Substernale Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to Substernale.

17. Anterior Superior Iliac Spine Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to right Anterior Superior Iliac Spine.

18. Symphysion Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to Symphysion.

19. Suprasternale-Acromion Distance: Measure the parallel distance with an anthropometer from Suprasternale to right and left Acromion.

20. Biacromial Diameter: Measure the distance with an anthropometer between the lateral edge of the right and left Acromions.

21. Mid-Chest Breadth: Measure with an anthropometer the breadth of the chest at a level mid-way between Suprasternale and Substernale perpendicular to the mid-sagittal plane.

22. Chest Breadth at Substernale: Measure with an anthropometer the breadth of the chest at Substernale.

23. Hip Breadth at Iliocristale: Measure with an anthropometer the boney breadth between the right and left Iliocristale landmarks perpendicular to the mid-sagittal plane.

24. Bispinous Diameter: Measure with an anthropometer the parallel distance between the right and left Anterior Superior Iliac Spines.

25. ASIS-Symphysion Distance: Measure with an anthropometer the parallel distance from Symphysion to right Anterior Superior Iliac Spine.

26. Bitrochanteric Breadth: Measure with an anthropometer the boney breadth between right and left Trochanterions perpendicular to the mid-sagittal plane.

27. Acromion-Radiale Length: Measure with an anthropometer the distance from Acromion to Radiale parallel to the long axis of the right upper limb.

28. Ball of Humerus-Radiale Length: Measure with an anthropometer the distance from Ball-of-Humerus to Radiale parallel to the long axis of the right upper limb.

29. Radiale-Stylion Length: Measure with an anthropometer the distance from Radiale to Stylion parallel to the long axis of the right lower arm.

30. Hand Length: Measure with sliding calipers the length of the hand from the distal wrist crease to Dactylion parallel to the long axis of the right hand.

31. Hand Breadth: Measure with sliding calipers the breadth of the right hand between the distal ends of Metacarpal II and Metacarpal V.

32. Hand Thickness: Measure with spreading calipers the maximum thickness of the right hand at the distal end of Metacarpal III.

33. Minimum Wrist Breadth: Measure with sliding calipers the

minimum breadth of the right wrist just proximal to the radial and ulnar styloid processes.

34. Forearm Depth: Measure with sliding calipers the maximum breadth of the right forearm at the same level as maximum forearm circumference.

35. Upper Arm Depth: Measure with sliding calipers the depth of the right upper arm at a level midway between the top of the shoulder and the inferior tip of the olecranon process.

36. Femur Length: Measure with an anthropometer the parallel distance from Trochanterion to Fibulare on the right leg.

37. Fibular Length: Measure with an anthropometer the parallel distance from Fibulare to the lateral Malleolus of the fibula on the right leg.

38. Tibia Length: Measure with an anthropometer the parallel distance from Tibiale to Sphyrion on the right leg.

39. Lower Leg Length: Measure with an anthropometer the parallel distance from Tibiale to the most distal point on the heel of the foot on the right leg.

40. Foot Length: Measure with an anthropometer the length of the right foot from the dorsal surface of the heel to the tip of the big toe along an axis parallel to the long axis of the foot.

41. Foot Breadth: Measure with sliding calipers the maximum breadth of the right foot at the level of the metatarsal-phalangeal joints.

42. Minimum Ankle Breadth: Measure with sliding calipers the minimum breadth of the right ankle proximal to the malleoli.

43. Maximum Calf Depth: Measure with sliding calipers the

maximum anterio-posterior depth at the level of maximum calf circumference on the right leg.

44. Upper Thigh Breadth: Measure with a beam anthropometer the breadth of the upper right thigh at the level of the crotch.

45. Head Breadth: Measure with spreading calipers the maximum horizontal breadth on the skull perpendicular to the mid-sagittal plane.

46. Head Length: Measure with spreading calipers the maximum length in the mid-sagittal plane between Glabella and Opisthocranion.

47. Bitragion Diameter: Measure with spreading calipers the distance between right and left Tragions.

48. Bigonial Diameter: Measure with spreading calipers the distance between right and left Gonions.

49. Mastoid-Crinion Length: Measure with the anthropometer the distance from the tip of the mastoid process to Crinion parallel to the mid-sagittal plane.

50. Head Circumference: With the tape passing just above Glabella, measure the maximum circumference of the head.

51. Mid-Sagittal Arc Length: Place the tape on Glabella and measure the arc length in the mid-sagittal plane to Nuchale.

52. Bitragion-Coronal Arc Length: Place the tape on left Tragion and measure the arc length to right Tragion in the Frontal Plane.

53. Mid-Neck Circumference: Measure the circumference of the neck with the tape passing inferior, but tangent to, the laryngeal prominence (Adam's Apple).

54. Chest Circumference at Mid-Chest: Measure the horizontal circumference at the level of the point on the anterior surface of the chest midway between Suprasternale and Substernale.

55. Chest Circumference at Substernale: Measure the horizontal circumference at the level of Substernale.

56. Hip Circumference, Iliocristale: Measure the horizontal circumference at the level of Iliocristale.

57. Buttocks Circumference at Trochanterion: Measure the horizontal circumference at the level of Trochanterion.

58. Upper Arm Circumference: Measure the circumference of the upper arm at the level of half the length of the upper limb in a plane perpendicular to the long axis of the right limb.

59. Maximum Forearm Circumference: Measure the maximum circumference of the forearm with the tape in a plane perpendicular to the long axis of the right limb.

60. Minimum Wrist Circumference: Measure the minimum circumference of the wrist at the level proximal to the styloid processes of the radius and ulna in a plane perpendicular to the long axis of the right forearm.

61. Upper Thigh Circumference: Measure the circumference of the thigh tangent to the crotch in a plane perpendicular to the long axis of the right thigh.

62. Maximum Calf Circumference: Measure the maximum circumference of the calf in a plane perpendicular to the long axis of the right lower leg.

63. Minimum Ankle Circumference: Measure the minimum circumference of the ankle at the level proximal to the malleoli of the tibia and fibula on a plane perpendicular to the long axis of the right lower leg.

B. FORTRAN Program for Computing 3-D Coordinate Locations of Anthropometric Landmarks

The programs in the following listings were written for use on an AMDAHL 470/V6 and run under the University of Michigan's operating system known as the Michigan Terminal System (or MTS). Much of the code is written in standard FORTRAN IV, however, occasional use is made of MTS-supplied system subroutines such as FREAD which is a free format data I/O utility or FORTRAN extensions peculiar to MTS such as "IF(EQUC......)."

The programs are:

MAIN -- which reads the x-y data, and calculates much of the 3-d information (following the algorithm discussed in the 1st Interim Report, Chapter 4.2). Additionally, main serves as the main program of the subroutines which follow.

RAD -- supplied a value of x in degrees, RAD returnes as the equivalent in radians.

DEG -- supplied a value of x in radians, DEG returns as the equivalent in Degrees.

COORD -- performs a portion of the calculations discussed in Chapter 4.2 of the 1st Interim Report which are performed repeatedly during the execution.

CORECT-- rotates and translates the x-y values read in from each x-ray into the same axis system, thus allowing x-rays to be placed on the digitizer without orienting them to the digitizer axis system.

ORIENT-- calculates for each x-ray digitized, the rotation and translation of points to be performed by CORECT. Thus both stereo-pairs are oriented mathematically into the same axis system by use of fiducial marks on the film.

RAXIS -- a subprogram which rotates and translates the 3-d points of targets which are in the primary axis system into the coordinates of the secondary axis system. Utilizing the Algorithm discussed in Chapter 4.1 of the 1st Interim Report.

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)           MAIN          09-28-77        18:45:55        PAGE 0001

              IMPLICIT REAL*8 (A-H,O-Z)
              DIMENSION XIN(3),YIN(3),XA(20),YA(20),XB(20),YB(20),IA(1)
              DIMENSION XOUT(20),YOUT(20),ZOUT(20)
              LOGICAL*1 BUF(20),NAME(24,20),XCHAR,YCHAR,EQUC
              REAL HTARG,THGT
        C.
        C.    HTARG="S" FILM TO OBJECT REFERENCE PLANE DISTANCE (CM)
        C.    THGT= FILM PLANE TO CALIBRATION DEVICE TARGET DISTANCE (CM)
        C.
        C.    A PROGRAM TO ANALIZE DIGITIZER DATA SENT FROM THE MSRI
        C.    NUMONICS DIGITIZET.
        C.    SEE J. FREEMAN OR H, GOLOMB AT MSRI FOR DETAILS.
        C.
        C.    09-09-77 MODIFIED FROM PDP-11/45 (MSRI) VERSION WRITTEN
        C.    BY JRF AND DHG
        C.
              DATA XCHAR/'X'/
              DATA YCHAR /'Y'/
              CALL FREAD(-2,'ENDF',1)
              HTARG=2.5781
              THGT=15.3381
            5 WRITE(2,999)
          999 FORMAT('&NEW DISTANCE VALUES (Y/N)?')
              READ(1,1003,END=500)BUF
         1003 FORMAT(20A1)
              IF(.NOT.EQUC(BUF(1),YCHAR)) GO TO 10
              WRITE(2,998)
          998 FORMAT('&S=')
              READ(1,997)HTARG
          997 FORMAT(G13.4)
              WRITE(2,996)
          996 FORMAT('&TARGET TO FILM PLANE DISTANCE (CM)=')
              READ(1,997)THGT
           10 WRITE(2,1000)
         1000 FORMAT('&ENTER STEREO BASE VALUE (CM-INCLUDE DECIMAL)?')
              READ(1,1001,END=500)B
         1001 FORMAT(F12.4)
              WRITE(2,1019)
         1019 FORMAT('&RT, LT ABIS THEN SYMPH FIRST (Y/N)?')
              READ(1,1003,END=10)BUF
              IPELV=0
              IF(EQUC(BUF(1),YCHAR))IPELV=1
           50 WRITE(2,1007)
         1007 FORMAT('0POSITION CALIBRATION X-RAY')
           60 WRITE(2,1008)
         1008 FORMAT('&TWO CROSS HAIR MARKS ON X OR Y AXIS?')
              READ(1,1003,END=5)BUF
              IAXIS=0
              IF(EQUC(BUF(1),XCHAR)) IAXIS=1
              IF(EQUC(BUF(1),YCHAR)) IAXIS=-1
              IF(IAXIS.EQ.0) GO TO 60
           70 WRITE(2,1009)
         1009 FORMAT('0ENTER TWO POINTS ON ONE AXIS, THEN THE THIRD')
              CALL FREAD('SCARDS','2R:',XIN(1),YIN(1),&60)
              CALL FREAD('SCARDS','2R:',XIN(2),YIN(2),&60)

MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)           MAIN          09-28-77        18:45:55        PAGE 0002

              CALL FREAD('SCARDS','2R:',XIN(3),YIN(3),&60)
        C.
        C.    CALL ORIENT
        C.
              CALL ORIENT(XIN,YIN,IAXIS,XERR,YERR,ANGLE)
              WRITE(2,1011)
         1011 FORMAT('0ENTER TWO DIAGONAL COORDINATES')
              CALL FREAD('SCARDS','2R:',X1,Y1)
              CALL FREAD('SCARDS','2R:',X2,Y2)
              CALL CORECT(X1,Y1,XERR,YERR,ANGLE)
              CALL CORECT(X2,Y2,XERR,YERR,ANGLE)
              D=(X1-X2)*(X1-X2)+(Y1-Y2)*(Y1-Y2)
              D=DSQRT(D)
              A=D*THGT/(D-17.98828)
              A=(A-THGT)/THGT
              WRITE(2,1012)
         1012 FORMAT('0ENTER CENTER TARGET COORDINATES')
              CALL FREAD('SCARDS','2R:',X1,Y1)
              CALL CORECT(X1,Y1,XERR,YERR,ANGLE)
              XE=-X1*A
              YE=-Y1*A
              D=A*THGT+THGT
              A=D-HTARG
        C.
        C.    NUMBER OF POINTS TO DIGITIZE
        C.
        C.THEN CALCULATE X,Y AND Z FOR SOME POINTS
        C.
           20 WRITE(2,1002)
         1002 FORMAT('&ENTER NUMBER OF POINTS TO DIGITIZE?')
              CALL FREAD('SCARDS','I V:',IA,1,&50)
              WRITE(2,1004)IA(1)
         1004 FORMAT('0ENTER ',I2,' NAMES'/)
              IAOUT=IA(1)
              DO 40 I=1,IAOUT
           35 WRITE(2,1005)I
         1005 FORMAT(1H&,I2,':')
           40 READ(1,1006,END=20)(NAME(J,I),J=1,24)
         1006 FORMAT(24A1)
           80 WRITE(2,1013)
         1013 FORMAT('&POSITION LEFT X-RAY, RESET SYSTEM AND HIT RETURN?')
              READ(1,1003,END=20)BUF
           90 WRITE(2,1008)
              READ(1,1003,END=80)BUF
              IAXIS=0
              IF(EQUC(BUF(1),XCHAR)) IAXIS=1
              IF(EQUC(BUF(1),YCHAR)) IAXIS=-1
              IF(IAXIS.EQ.0) GO TO 90
           95 WRITE(2,1009)
              CALL FREAD('SCARDS','2R:',XIN(1),YIN(1),&95)
              CALL FREAD('SCARDS','2R:',XIN(2),YIN(2),&95)
              CALL FREAD('SCARDS','2R:',XIN(3),YIN(3),&95)
              CALL ORIENT(XIN,YIN,IAXIS,XERR,YERR,ANGLE)
              IAOUT=IA(1)
              DO 100 I=1,IAOUT
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)          MAIN          09-28-77          18:45:55          PAGE P003

            WRITE(2,1014)(NAME(J,I),J=1,24)
       1014 FORMAT(1H&,24A1)
            CALL FREAD('SCARDS','2R:',XA(I),YA(I))
        100 CALL CORECT(XA(I),YA(I),XERR,YERR,ANGLE)
        105 WRITE(2,1015)
       1015 FORMAT('&POSITION RIGHT X-RAY, RESET SYSTEM AND ENTER RETURN?')
            READ(1,1003,END=105)BUF
        110 WRITE(2,1008)
            READ(1,1003,END=105)BUF
            IAXIS=0
            IF(EQUC(BUF(1),XCHAR)) IAXIS=1
            IF(EQUC(BUF(1),YCHAR)) IAXIS=-1
            IF(IAXIS.EQ.0) GO TO 110
        115 WRITE(2,1009)
            CALL FREAD('SCARDS','2R:',XIN(1),YIN(1),&115)
            CALL FREAD('SCARDS','2R:',XIN(2),YIN(2),&115)
            CALL FREAD('SCARDS','2R:',XIN(3),YIN(3),&115)
            CALL ORIENT(XIN,YIN,IAXIS,XERR,YERR,ANGLE)
            IAOUT=IA(1)
            DO 120 I=1,IAOUT
            WRITE(2,1014)(NAME(J,I),J=1,24)
            CALL FREAD('SCARDS','2R:',XB(I),YB(1))
        120 CALL CORECT(XB(I),YB(I),XERR,YERR,ANGLE)
      C.
      C.    NOW CALCULATE
      C.
            IAOUT=IA(1)
            DO 130 I=1,IAOUT
            OT1=D*(B/2.0)/A
            OT2=-1.0*OT1
            Y1=(YA(I)+YB(I))*.5
            CALL COORD(B,OT1,OT2,XA(I),XB(I),Y1,A,D,X,Y,Z)
            XTEMP=X-(B*0.5)
      C.
      C.    NOW ITERATE - FIRST ADJUST OT
      C.
            B=HTARG
            AT=XE*B/A
            OT1=OT1+AT
            OT2=OT2+AT
      C.
      C.    CORRECT X VALUES
      C.
            ITRY=0
            AT=XE*(Z+HTARG)/(A-Z)
            XA(I)=XA(I)+AT
            XB(I)=XB(I)+AT
      C.
      C.    CORRECT Y
      C.
            AT=YE*(Z+HTARG)/(A-Z)
            Y1=Y1+AT
            CALL COORD(B,OT1,OT2,XA(I),XB(I),Y1,A,D,X3,Y3,Z3)
            X=X3
            Y=Y3
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)          MAIN          09-28-77          18:45:55          PAGE P004

            Z=Z3
            XTEMP=X-(B*0.5)
            XOUT(I)=XTEMP
            YOUT(I)=Y
            ZOUT(I)=Z
        130 CONTINUE
            IF(IPELV.EQ.1) GO TO 140
            IAOUT=IA(1)
            DO 135 I=1,IAOUT
            WRITE(2,1018)
       1018 FORMAT(/'&ADJUSTED COORDINATES: ')
        135 WRITE(2,1017)(NAME(J,I),J=1,24),XOUT(I),YOUT(I),ZOUT(I)
       1017 FORMAT(1H+,24A1/' X=',G13.4,' Y=',G13.4,' Z=',G13.4)
            GO TO 60
        140 CALL RAXIS(XOUT,YOUT,ZOUT,IA(1),NAME)
            GO TO 50
        500 STOP
            END
 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =       57
 *STATISTICS*    SOURCE STATEMENTS =       152,PROGRAM SIZE =     7184
 *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)        RAD        09-28-77      18:45:56      PAGE P001

 0001              FUNCTION RAD(X)
 0002              REAL*8 RAD,X
 0003              RAD=X/57.29577951
 0004              RETURN
 0005              END
  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = RAD      , LINECNT =       57
  *STATISTICS*    SOURCE STATEMENTS =        5,PROGRAM SIZE =       308
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)        DEG        09-28-77      18:45:57      PAGE P001

 0001              FUNCTION DEG(X)
 0002              REAL*8 DEG,X
 0003              DEG=X*57.29577951
 0004              RETURN
 0005              END
  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = DEG      , LINECNT =       57
  *STATISTICS*    SOURCE STATEMENTS =        5,PROGRAM SIZE =       308
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)        COORD      09-28-77      18:45:58      PAGE P001

 0001              SUBROUTINE COORD(B,OT1,OT2,XA,XB,Y1,A,D,X,Y,Z)
 0002              IMPLICIT REAL*8 (A-Z)
             C.
             C.   TO CALCULATE 3-D COORDINATES
             C.
 0003              XP1=OT1+XA
 0004              XP2=OT2+XB
 0005              KA=B/(XP1-XP2)
 0006              X=XP1*KA
 0007              Y=Y1*KA
 0008              Z=A-D*KA
 0009              RETURN
 0010              END
  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = COORD    , LINECNT =       57
  *STATISTICS*    SOURCE STATEMENTS =       10,PROGRAM SIZE =       664
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)        CORECT     09-28-77      18:45:58      PAGE P001

 0001              SUBROUTINE CORECT(X,Y,XE,YE,ANGLE)
 0002              IMPLYCIT REAL*8 (A-H,O-Z)
 0003              TEMP=X
 0004              X=X*DCOS(ANGLE)+Y*DSIN(ANGLE)
 0005              Y=Y*DCOS(ANGLE)-TEMP*DSIN(ANGLE)
 0006              X=X+XE
 0007              Y=Y+YE
 0008              RETURN
 0009              END
  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = CORECT   , LINECNT =       57
  *STATISTICS*    SOURCE STATEMENTS =        9,PROGRAM SIZE =       558
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)          ORIENT          09-28-77          18:45:59          PAGE P001

            SUBROUTINE ORIENT(X,Y,IAXIS,XERR,YERR,ALPHA)
            IMPLICIT REAL*8 (A-H,O-Z)
            DIMENSION X(3),Y(3)
            REAL*8 LAMBDA
      C.
      C.   TO ORIENT COORDINATE SYSTEM OF X-RAY WITH THAT OF THE
      C.   HSRI - BIOMED NUMONICS DIGITIZER READ HEAD,
      C.
      C.   SLOPE AND Y INTERCEPT OF LINE WITH TWO POINTS
      C.
            IF(X(1).EQ.X(2).OR.Y(1).EQ.Y(2)) GO TO 800
            SLOPE=(Y(1)-Y(2))/(X(1)-X(2))
            YCPT=Y(1)-SLOPE*X(1)
            IF(IAXIS.EQ.-1) GO TO 600
      C.
      C.   TWO POINTS ON X AXIS
      C.
            IF(Y(3).GT.Y(1).OR.Y(3).GT.Y(2)) GO TO 10
            SIGN=+1.0
            IF(Y(1).LT.Y(2)) GO TO 2
            X1=X(2)
            Y1=Y(2)
            GO TO 15
          2 X1=X(1)
            Y1=Y(1)
            GO TO 15
         10 SIGN=-1.0
            IF(Y(1).GT.Y(2)) GO TO 12
            X1=X(2)
            Y1=Y(2)
            GO TO 15
         12 X1=X(1)
            Y1=Y(1)
         15 X2=X(3)
            Y2=Y(3)
      C.
      C.   LOCATE ORIGIN AND DESCRIBE ROTATION
      C.
            BETA=DATAN((Y1-Y2)/(X1-X2))
            ALPHA=DATAN((Y(1)-Y(2))/(X(1)-X(2)))
            THETA=90.0-DABS(DEG(BETA))-DABS(DEG(ALPHA))
            D1=(X1-X2)*(X1-X2)+(Y1-Y2)*(Y1-Y2)
            D1=DSQRT(D1)
            D=D1*DCOS(RAD(THETA))
            D3=D*DCOS(ALPHA)
            Y0=Y2+D3*SIGN
            X0=(Y0-YCPT)/SLOPE
            TEMP=DEG(ALPHA)
            ALPHA=DSIGN(ALPHA,SLOPE)
            GO TO 900
      C.
      C.   TWO POINTS ON Y AXIS
      C.
        600 IF(X(3).GT.X(1).OR.X(3).GT.X(2)) GO TO 610
            SIGN=+1.0
```

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MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)          ORIENT          09-28-77          18:45:59          PAGE P002

            IF(X(1).LT.X(2)) GO TO 602
            X1=X(2)
            Y1=Y(2)
            GO TO 615
        602 X1=X(1)
            Y1=Y(1)
            GO TO 615
        610 SIGN=-1.0
            IF(X(1).GT.X(2)) GO TO 612
            X1=X(2)
            Y1=Y(2)
            GO TO 615
        612 X1=X(1)
            Y1=Y(1)
        615 X2=X(3)
            Y2=Y(3)
      C.
      C.   LOCATE ORIGIN AND DESCRIBE POTATION
      C.
            BETA=DATAN((X1-X2)/(Y1-Y2))
            ALPHA=DATAN((X(1)-X(2))/(Y(1)-Y(2)))
            THETA=90.0-DABS(DEG(ALPHA))-DABS(DEO(BETA))
            D1=(X2-X1)*(X2-X1)+(Y2-Y1)*(Y2-Y1)
            D1=DSQRT(D1)
            D=D1*DCOS(RAD(THETA))
            D3=D*DCOS(ALPHA)
            X0=X2+D3*SIGN
            Y0=SLOPE*X0+YCPT
            TEMP=DEG(ALPHA)
            ALPHA=-1.0*DSIGN(ALPHA,SLOPE)
            GO TO 900
        800 ALPHA=0.0
            XERR=-X(1)
            YERR=-Y(3)
            IF(IAXIS.EQ.1)XERR=-X(3)
            IF(IAXIS.EQ.1)YERR=-Y(1)
            RETURN
        900 XERR=-1.0*(X0*DCOS(ALPHA)+Y0*DSIN(ALPHA))
            YERR=-1.0*(Y0*DCOS(ALPHA)-X0*DSIN(ALPHA))
            RETURN
            END
 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = ORIENT  , LINECNT =      57
 *STATISTICS*    SOURCE STATEMENTS =      78,PROGRAM SIZE =     2262
 *STATISTICS*  NO DIAGNOSTICS GENERATED
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MICHIGAN TERMINAL SYSTEM FORTRAN G(21.8)          RAXIS          09-28-77          18:46:00          PAGE P001

0001              SUBROUTINE RAXIS(XIN,YIN,ZIN,N,NAME)
0002              REAL*8 XIN(20),YIN(20),ZIN(20)
0003              REAL*8 A(3),B(3),C(3),D,T,X,Y,Z,BX,BY,BZ
0004              LOGICAL*1 NAME(24,20)
            C.
            C.    CALCULATE Y-AXIS DIRECTIONAL COSINES
            C.
0005              D=(XIN(1)-XIN(2))*(XIN(1)-XIN(2))+(YIN(1)-YIN(2))*(YIN(1)-YIN(2))+
                 1(ZIN(1)-ZIN(2))*(ZIN(1)-ZIN(2))
0006              D=DSQRT(D)
0007              B(1)=(XIN(2)-XIN(1))/D
0008              B(2)=(YIN(2)-YIN(1))/D
0009              B(3)=(ZIN(2)-ZIN(1))/D
            C.
            C.    CALCULATE T
            C.
0010              T=((XIN(3)-XIN(2))*(XIN(2)-XIN(1))+(YIN(3)-YIN(2))*(YIN(2)-YIN(1))
                 1+(ZIN(3)-ZIN(2))*(ZIN(2)-ZIN(1)))/(D*D)
0011              X=XIN(2)+T*(XIN(2)-XIN(1))
0012              Y=YIN(2)+T*(YIN(2)-YIN(1))
0013              Z=ZIN(2)+T*(ZIN(2)-ZIN(1))
0014              WRITE(2,110)X,Y,Z
0015          110 FORMAT('0NEW ORIGIN AT:',/' X=',F8.3/' Y=',F8.3/' Z=',F8.3)
            C.
            C.    CALCULATE X-AXIS DIRECTIONAL COSINES
            C.
0016              D=(XIN(3)-X)*(XIN(3)-X)+(YIN(3)-Y)*(YIN(3)-Y)+(ZIN(3)-Z)*(ZIN(3)-Z
                 1)
0017              D=DSQRT(D)
0018              A(1)=(XIN(3)-X)/D
0019              A(2)=(YIN(3)-Y)/D
0020              A(3)=(ZIN(3)-Z)/D
            C.
            C.    CALCULATE Z AXIS DIRECTIONAL COSINES
            C.
0021              C(1)=A(2)*B(3)-A(3)*B(2)
0022              C(2)=A(3)*B(1)-A(1)*B(3)
0023              C(3)=A(1)*B(2)-A(2)*B(1)
            C.
            C. RECALCULATE DATA TO NEW COORDINATE SYSTEM
            C.
0024              DO 98 I=1,N
0025              BX=XIN(I)-X
0026              BY=YIN(I)-Y
0027              BZ=ZIN(I)-Z
0028              CZ=(A(1)*BX+A(2)*BY+A(3)*BZ)*(-1.0)
0029              CY=(B(1)*BX+B(2)*BY+B(3)*BZ)
0030              CX=(C(1)*BX+C(2)*BY+C(3)*BZ)
0031              WRITE(2,104)(NAME(J,I),J=1,24)
0032          104 FORMAT('0TARGET: ',24A1)
0033              WRITE(2,105)XIN(I),CX,YIN(I),CY,ZIN(I),CZ
0034          105 FORMAT(' OLD X:',F10.3,'   NEW X:',F10.3/           ' OLD Y:',F10.
                 13,'   NEW Y:',F10.3/           ' OLD Z:',F10.3,'   NEW Z:',F10.3)
0035           98 CONTINUE
0036              WRITE(2,150)

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0037          150 FORMAT(///)
0038              RETURN
0039              END
  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = RAXIS   , LINECNT =       57
  *STATISTICS*     SOURCE STATEMENTS =        39,PROGRAM SIZE =       1612
  *STATISTICS*  NO DIAGNOSTICS GENERATED

NO STATEMENTS FLAGGED IN THE ABOVE COMPILATIONS.
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C. Experimental Outline for Systems Anthropometry Data Collection

		Films
1.	X-Ray Calibration	3
2.	X-Ray Survey of Specimen	4

1) A-P Lumbar
2) A-P Pelvis
3) A-P Femur, including Knee
4) Lateral Pelvis

3. Anthropometry

4. Surface-Internal Landmark Correlation

   1) Specimen in supine position on 1/4" plywood sheet on x-ray table, wedge blocks above and below pelvis on both sides;

      a) Surface Landmarks on Pelvis and Femur

         (1) Right ASIS
         (2) Left ASIS
         (3) Symphysion
         (4) Right Pubic Tubercle
         (5) Left Pubic Tubercle
         (6) Right Greater Trochanter-Trochanterion

      b) Stereo-pair — 2

         (1) A-P Pelvis--1.1. Landmarks

      c) Internal Landmarks

         (1) Right ASIS
         (2) Left ASIS
         (3) Symphysion
         (4) Right Pubic Tubercle
         (5) Left Pubic Tubercle
         (6) Right Greater Trochanter--Trochanterion
         (7) Right Greater Trochanter--2 landmarks for axis system

d) Stereo-pairs

(1) A-P Pelvis--Landmarks

2) Specimen in prone position on 1/4" plywood sheet on x-ray table, with wedge blocks above and below pelvis on both sides.

a) Surface Landmarks on L/5 and Pelvis

(1) Right PSIS

(2) Left PSIS

(3) Spine amidway between Rt + Lt PSIS Landmarks.

b) Stereo-Pair 2

(1) P-A Pelvis--SURFACE Landmark

c) Internal Landmarks

(1) Spine of L5

(2) Right PSIS

(3) Left PSIS

(4) Spine of S1

d) Stereo-Pair 2

(1) P-A Pelvis--INTERNAL Landmark

5. Preparation for Motion Study

1) With specimen in autopsy room, in prone position, mount on short-board rigidly.

2) X-Ray calibration check 3

3) Position specimen on x-ray table in supine position, clamp specimen board to x-ray table with C-clamps and 2" x 4" boards.

a) Stereo-Pairs--PLANAR MOTION (FRONTAL)

(1) Initial position--feet together (@90°) 2

(2) Abduction--Aduction 14

(a) 100°

(b) 110°

(c) 120°

(d) 130°

(e) 140°

(f) 150°

(g) 160°

b) Stereo-Pairs--PLANAR MOTION (TRANSVERSE)

(1) Initial Position--foot straight up (0°) 2

(2) Rotation 10

(a) 30° Outboard

(b) 60° "

(c) 90° "

(d) 30° Inboard

(e) 60° "

4) Position specimen on x-ray table in lateral position, with iron door stop, C-clamps, and 2 x 4's, and shim torso with blocks.

a) Stereo-Pairs--PLANAR MOTION (PARA SAGITTAL)

(1) Initial position--leg in standing position (0°) 2

(2) Flexion 12

(a) 20°

(b) 40°

(c) 60°

(d) 80°

(e) 100°

(f) 120°

D. Landmark Definitions used in X-Ray Stereo-Photogrammetry Study

Anterior Superior Iliac Spine (ASIS): With the specimen in the supine anatomical position, palpate and mark the most anterior point on the superior iliac spine.

Symphysion: With the specimen in the supine anatomical position palpate and mark the most superior point on the ventral rim of the pubic symphysis.

Pubic Tubercle: With the specimen in the supine anatomical position, palpate and mark the most anterior point on the pubic tubercle.

Trochanterion: With the specimen in the supine anatomical position, palpate and mark the most superior point on the greater trochanter of the femur.

L5 Spine: With the specimen in the prone anatomical position, palpate and mark the most posterior point on the dorsal spine of the fifth lumbar vertebra.

S1 Spine: With the specimen in the prone anatomical position, palpate and mark the most posterior point on the first dorsal spine of the sacral body.

Posterior Superior Iliac Spine (PSIS): With the specimen in the prone anatomical position, palpate and mark the most posterior point on the superior iliac spine.