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THE UNIVERSITY OF MICHIGAN

TO: 6570th Aerospace Medical Research
Laboratory
ATTN: MRHA, Mr. K. Kennedy
Contract F33615-70-C-1777
Wright-Patterson AFB, Ohio 45433

FROM: Dr. R.G. Snyder and Dr. D.B. Chaffin
Co-Principal Investigators

SUBJECT: 3rd Quarterly Report: Link System of the Human Torso

A third quarterly report is submitted in accordance with Exhibit B of the above contract, dated 30 September, 1969. This report describes research activities and progress for the period 15 December, 1970 through 15 March, 1971.

LINK SYSTEM OF THE HUMAN TORSO

Quarterly Report No. 3
15 March, 1971

Submitted to: 6570th Aerospace Medical Research Laboratory
ATTN: MRHA, Mr. K. Kennedy
Contract F33615-70-C-1777
Wright-Patterson Air Force Base, Ohio 45433

Biomedical Department
Biosciences Division
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I. SUMMARY OF PROGRESS IN ANALYZING LIVING SUBJECT DATA

At this report writing, the following has been accomplished:

A. Anthropometry

1. Twenty-three subjects have been measured for 63 pre-determined dimensions and 4 skinfold determinations. An additional 5 measurements have been included which may provide supplementary information of a bilateral symmetry nature.
2. Anthropometric data has been transferred from individual work forms to a master tabulation for all subjects.
3. To date x-ray validation of bony landmarks has shown good accuracy of surface palpation techniques with overlying tissue thickness and nature of the landmark major factors influencing variations.

B. Photogrammetric Studies

1. Twenty one subjects have been filmed.
2. Three sets of films have been read, coded, and punched and have been converted to three-space coordinate data by special computer programs.
3. Regression models have been developed to be used when the remainder of the data is punched.

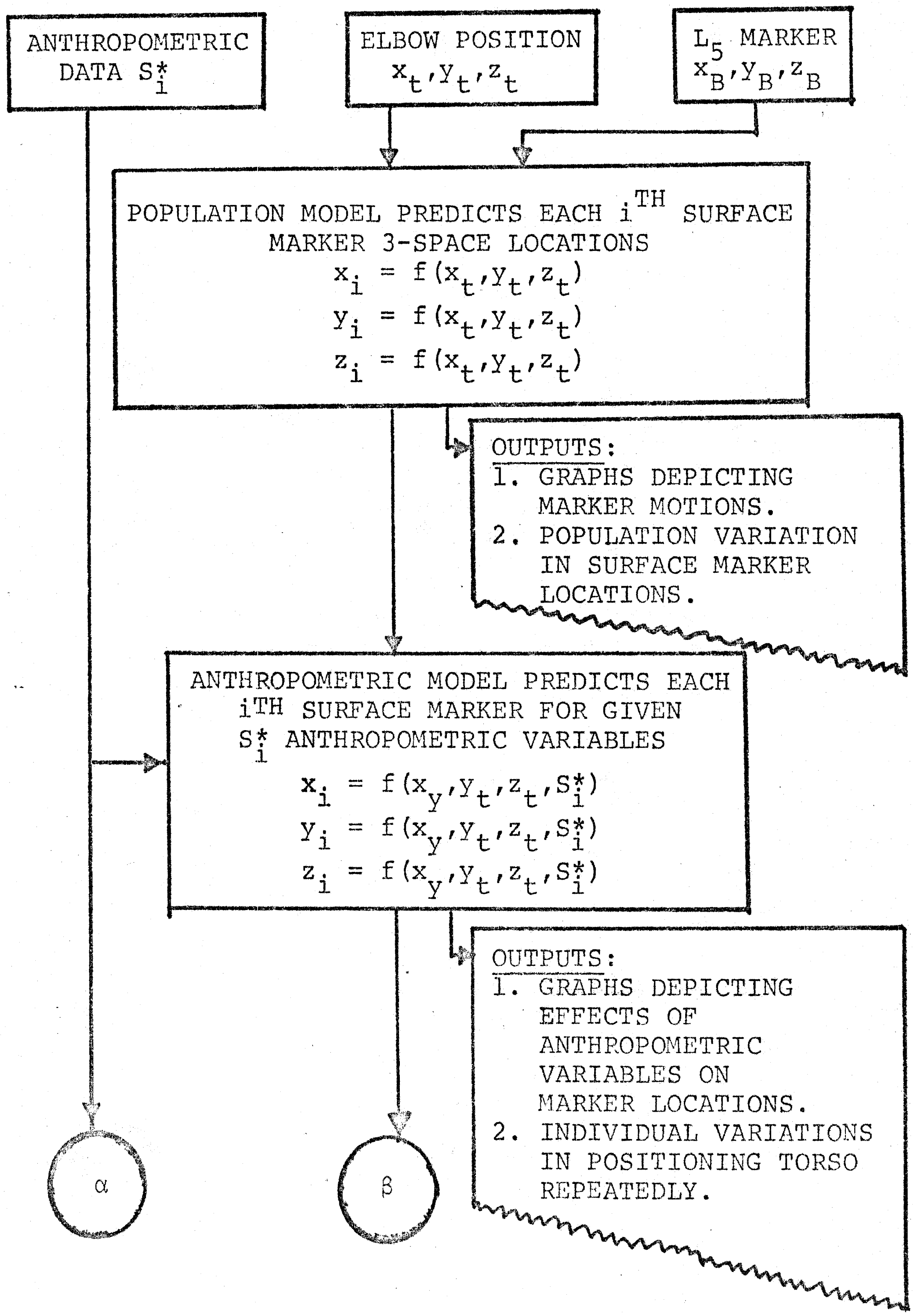
4. Plots of the data available to date have been made.
5. A general procedure for integrating anthropometric data, x-ray data, and photogrammetry data has been formulated, as illustrated in the flow chart - Figure 1.
6. Some illustrations of how the data would be formulated for design purposes have been developed, as is presented in this report.

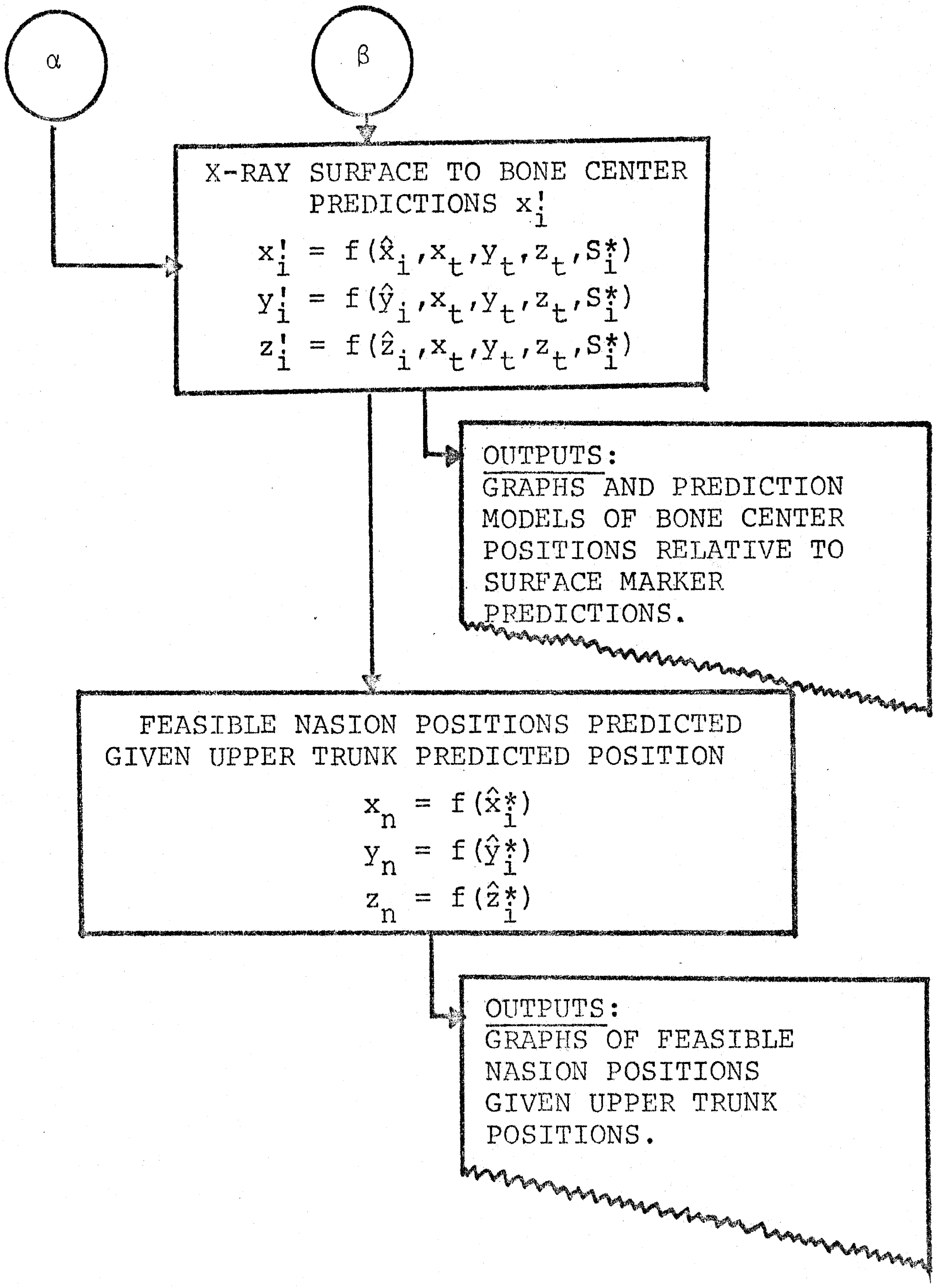
C. X-Ray Studies

1. Twenty-one subjects have been x-rayed.
2. All x-rays (189) have been read, coded, and the reference marks and bone position data have been punched on IBM cards.
3. All shoulder x-ray data has been reduced to coordinate data, which has then been converted to a series of vectors depicting point-to-point orientations.
4. Some shoulder data has been plotted, as in Figure 2, to determine which variables will provide meaningful regressions.

FIGURE 1

TORSO MOBILITY PREDICTION MODEL




α
β
X-RAY SURFACE TO BONE CENTER PREDICTIONS x_i'
$x_i' = f(\hat{x}_i, x_t, y_t, z_t, S_i^*)$
$y_i' = f(\hat{y}_i, x_t, y_t, z_t, S_i^*)$
$z_i' = f(\hat{z}_i, x_t, y_t, z_t, S_i^*)$
OUTPUTS:
GRAPHS AND PREDICTION MODELS OF BONE CENTER POSITIONS RELATIVE TO SURFACE MARKER PREDICTIONS.
FEASIBLE NASION POSITIONS PREDICTED GIVEN UPPER TRUNK PREDICTED POSITION
$x_n = f(\hat{x}_i^*)$
$y_n = f(\hat{y}_i^*)$
$z_n = f(\hat{z}_i^*)$
OUTPUTS:
GRAPHS OF FEASIBLE NASION POSITIONS GIVEN UPPER TRUNK POSITIONS.

II. INTRODUCTION

The following reports progress for the period 15 December, 1970, through 15 March, 1971. This phase of the study may be characterized as primarily involving the collection of data. It is based upon the initial investigation and experimental design outlined in the initial Quarterly Report of September, 1970, and the subsequent design of computer programs, subject selection and anthropometry technique determinations involved in the second Quarterly Report of December, 1970. As pointed out earlier, the initial findings that gross dissection of a cadaver would not provide as useful joint information as originally assumed, and the subsequent discovery of unexpected limitations of x-ray requirements and utility due to film and tissue density problems, which could not be technically resolved, were unpredicted. Our early decision to add photogrammetrics to the design has continued to prove to be a valid and wise judgement. While it is still too early in the study to predict results, at this point it is apparent that we should not only provide the data set forth in the original objectives, but we have already collected substantially more information than was anticipated. For example, instead of being capable of analyzing only 16 body positions for each subject, 35 positions for each subject have been analyzed. This has been possible due to the off-line Data Coder System described in the Second Quarterly Report, being available for the project. This has increased the total data, thus assuring an increase in the statistical confidence of the torso position prediction models described in the following.

III. SUBJECT ANTHROPOMETRY

In the second Quarterly Report a rather detailed discussion was presented relative to the statistical design and selection of test subjects. At that time an experimental subject pool had been established consisting of 75 male students, on which preliminary measures of height, weight, and sitting height were taken. The purpose of this pool, which has since been increased to about 100 subjects, was to allow a preliminary screening and final subject selection based upon a one-variable statistical design after Churchill. In addition eight subjects had been completely measured, x-rayed, and subjected to the photogrammetric series as designed. During the past quarterly period work scheduled in the Anthropometry portion of this study has consisted almost entirely of data gathering. Since the final analysis and evaluation of subject data has just been initiated, only a brief description of the data gathering phase will be included at this time.

A total of 22 selected male subjects, of the 25 required, have now been measured to match the statistical design shown in Table I. As indicated by this tabulation two categories of stature have extra subjects and four require further subjects. These subjects remaining to be measured are scheduled during this next week, coinciding with preparation and forwarding of this Quarterly report, and although data from these additional subjects are not included at this time, it is anticipated that final anthropometric data collection will actually be complete by the time this report is received.

TABLE I

STATISTICAL BASIS FOR SUBJECT SELECTION BASED UPON SINGLE VARIABLE OF STATURE TO MATCH 1967 AIR FORCE POPULATION

STATURE (CM)	USAF (1967)	%	X25	SAMPLE REQUIRED	SAMPLE OBTAINED
162.75 - 165.74	48	2.01	.50	1	1
165.75 - 168.74	132	5.53	1.38	1	1
168.75 - 171.74	237	9.93	2.48	2	2
171.75 - 174.74	401	16.81	4.20	4	4
174.75 - 177.74	443	18.57	4.64	5	4*
177.75 - 180.74	459	19.24	4.81	5	2*
180.75 - 183.74	309	12.95	3.24	3	4
183.75 - 186.74	198	8.3	2.08	2	4
186.75 - 189.74	117	4.9	1.23	1	0*
189.75 - 192.74	41	1.71	.43	1	0*
	2385			25	22

*Additional subjects needed to complete these categories.

This table also shows the actual matching to date based upon the criterion of stature alone for comparison between the 1967 USAF population and the U.M. subjects. A 23rd subject was measured and photogrammetric data completed, however, was omitted from tabulation here since his stature (197.0 cm) was excessive.

Table II presents a preliminary comparison of means and ranges of selected body dimensions found to date between the Air Force population as measured in either 1967 or 1950, and the U.M. subjects. Since several categories of subjects, including the two of greatest stature, have not yet been measured nor data added, this tabulation is provided only to give an approximation of the nature of the sample anthropometry to date. So far the U.M. subject ranges within each measurement are within the Air Force extremes, with the single exception of chest circumference. For this measurement one subject, a former weight-lifter, exceeds by 31.6 cm the 99th percentile value found in the 1967 Air Force Survey. Some discrepancies between the U.M. and 1950 Air Force data are believed due to differing definitions of landmarks employed. An example is bitrochanteric diameter (or breadth), not given in the 1950 study. "Hip breadth" is given in the 1950 study and listed for comparison, realizing that these are technically probably different measurements. U.M. subject stature and weight means are lower than for the 1967 Air Force population means. It may be expected that the mean for stature will more closely approximate that of the Air Force subjects when the two taller subjects yet to be measured are included. The weight discrepancy to date between the means of these two populations primarily reflects the difference between an older military population and the younger student population from which our sample is drawn. It would be premature to attempt further evaluation at this point before all subjects are measured and data included.

A predictive model including anthropometric variables will be developed during the final phase of this study. A detailed description of the procedure is provided in the section discussing Photogrammetric Analysis Technique. This Anthropometric Model will review inter-correlations of each of the 67 anthropometric variables to determine the set which can validly predict variables.

TABLE II

PRELIMINARY COMPARISON OF MEANS AND RANGES OF SELECTED BODY DIMENSIONS BETWEEN U.M. SUBJECTS (23) AND AIR FORCE POPULATION (2385) FOR THOSE MEASUREMENTS TAKEN IN EITHER 1967 OR 1950 AIR FORCE SURVEYS

MEASUREMENT	USAF RANGE (YEAR) 1-99th PERCENTILE	U.M. RANGE	MEANS USAF	MEANS U.M.
1. Stature	163.2 - 191.9 (1967)	163.5 - 186.5	177.34	176.36
2. Weight	127.5 - 227.7 (1967)	138.5 - 221.0	173.60	161.20
3. Right Tragion	148.4 - 176.9 (1950)			
4. Left Tragion	148.4 - 176.9 (1950)	151.0 - 172.6	162.36	162.75
5. Nasal Root Depression	150.9 - 179.6 (1950)	153.4 - 177.6	164.97	164.62
6. Cervicale (C_7)	138.2 - 166.1 (1967)	140.9 - 160.5	152.06	150.62
7. Suprasternale	132.5 - 158.4 (1967)	134.3 - 152.6	145.20	143.62
8. Right Acromion	131.8 - 158.4 (1967)	134.6 - 156.0	145.21	144.55
9. Left Acromion	131.8 - 158.4 (1967)	134.6 - 157.1	145.21	145.25
10. Biacromial Breadth	36.0 - 45.3 (1967)	36.0 - 43.0	40.73	39.49
11. Nipple Height	117.1 - 141.6 (1967)	117.9 - 136.9	129.24	128.48
12. Iliocristale Height	97.9 - 120.5 (1967)	101.0 - 114.0	109.15	106.84
13. Right Trochanterion	84.0 - 104.5 (1967)	84.6 - 97.6	93.96	90.76
14. Left Trochanterion	84.0 - 104.5 (1967)	82.7 - 98.3	93.96	90.73
15. Bitrochanteric Diameter	28.7 - 38.5 (1950)	29.7 - 38.3	33.45	32.83
16. Hand-Forearm Length	43.2 - 52.6 (1950)	45.4 - 52.9	47.91	48.16
17. Foot Length	24.3 - 29.8 (1967)	24.6 - 27.6	27.03	26.43
18. Head Circumference	54.4 - 61.0 (1967)	54.7 - 60.5	57.52	57.68
19. Chest Circumference	84.8 - 114.4 (1967)	90.1 - 146.0	98.55	96.95
20. Wrist Circumference	15.7 - 20.4 (1967)	15.5 - 18.5	17.59	16.93
21. Calf Circumference	31.6 - 42.6 (1967)	34.2 - 39.4	37.19	37.05
22. Ankle Circumference	19.6 - 25.6 (1967)	20.0 - 26.6	22.41	23.31
23. Sitting Height	86.2 - 100.6 (1967)	84.7 - 97.0	93.18	92.19
24. Acromion	54.4 - 67.7 (1967)	53.4 - 65.5	61.05	59.51
25. Buttock-Knee Length	54.3 - 67.3 (1967)	55.1 - 66.4	60.40	59.63
26. Knee Height	50.1 - 61.9 (1967)	51.5 - 58.5	55.76	55.14

IV. ANALYSIS OF X-RAY AND PHOTOGRAMMETRY DATA

As presented in the First and Second Quarterly Reports, the determination of torso mobility is to be based on a rigorous analysis of human configuration data obtained from both controlled X-rays and photographs of volunteers performing selected torso positions. This section describes the specific analysis techniques being employed, as well as presenting an overview of how the final torso mobility data will be presented for design reference.

OFF-SET X-RAY ANALYSIS TECHNIQUE

As stated in both the First and Second Quarterly Reports, the off-set X-ray procedure was employed to ascertain how the specific body surface markers were located in relation to adjacent palpable bones and assumed bone centers-of-rotation, for anthropometrically different individuals performing selected torso positions. The Second Quarterly Report also described the surface and bone points chosen for inclusion in the study.

At the writing of this report, 21 subjects have been X-rayed, resulting in 189 X-rays. These have been "read and coded," meaning that the surface and bone reference points have been measured on each in relation to a set of base reference points projected onto the X-rays at the same time as the subject's exposure. The base reference points provided a means to calibrate distances and anode angles, similar to that described in the Technical Appendix attached to the Second Quarterly Report. Thus the X-ray data taking phase is considered to be completed.

The analysis of the X-ray data has progressed such that all of the shoulder X-ray surface and bone position data have been converted to three space coordinates relative to the right anterior superior illiac spines (a typical display of the data from the first subject analyzed was presented in Table XII of the Second Quarterly Report). Graphs of this data have been prepared to assist in checking the program, and these have confirmed that the program is correctly predicting the body configuration for the various selected elbow positions. A typical lateral plot of the data (one-half scale) is displayed in Figure 2.

All of the shoulder X-ray bone and surface marker data have been processed by a second computer program which develops vector distances and directions that describe the various relative bone and surface marker positions. At present these vectors are being evaluated graphically and by simple curvilinear regressions to determine what combination of them can be most efficiently used to predict the bone link centers, given the surface marker positions. As an example of this, a

NOTE:

REF. POINTS ARE IDENTIFIED ON PAGE 24 OF <u>SECOND QUARTER REPORT</u>

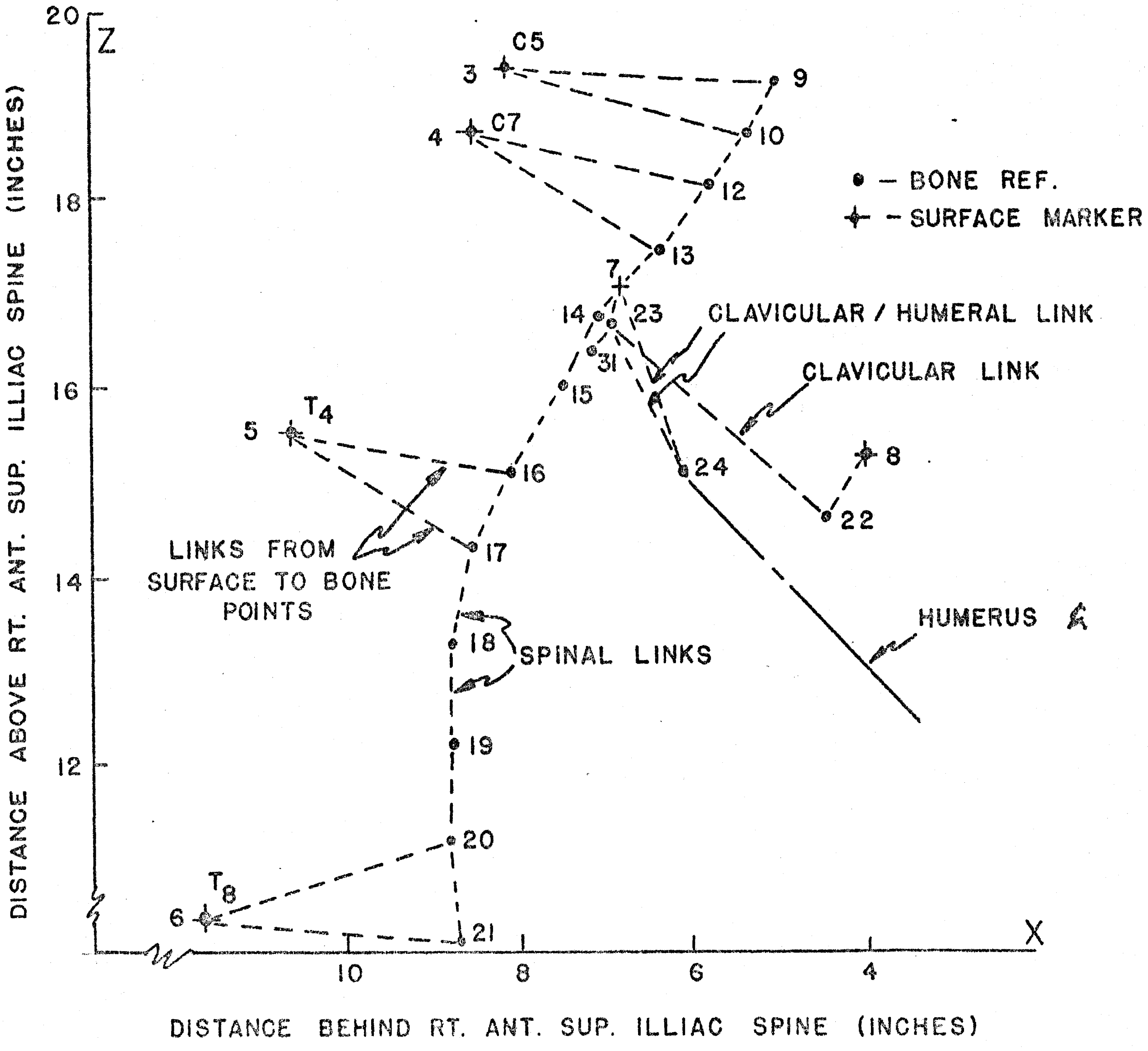


FIGURE 2

LATERAL VIEW OF THORACIC AND LOWER CERVICAL AREAS FOR SUBJECT #28 IN POSITION #32 graph showing how the C7 spine marker (cervicale) moves in respect to the C7/T_1 interspace for the five horizontal arm positions is presented in Figure 3. Once a set of vectors is established which relates the surface markers to bone centers for the general population, selected anthropometric variables (e.g., skin fold thicknesses and bone breadth dimensions are major a priori variables) will be added to the regressions to determine their contributions to the variance in the vector distances and directions.

The result of the preceding analysis will be a set of prediction models (e.g., curvilinear regressions) which depict the expected bone center positions, given the positions of the body surface markers, a few anthropometric variables, and the arm position relative to the torso. Because the prediction models will be computationally difficult to use for design purposes, a set of graphs will be developed to depict how the assumed bone centers move relative to the surface markers. Thus, given the torso bone surface marker positions as a function of the arm positions and anthropometry (as presented in the next subsection), and the bone center predictions from the X-rays, a designer is furnished with the complete set of information necessary to describe how both the "hard" external surface of the body moves, and how the internal bones move relative to the surface reference points. The resulting regression models or graphs can then be used by a designer to,

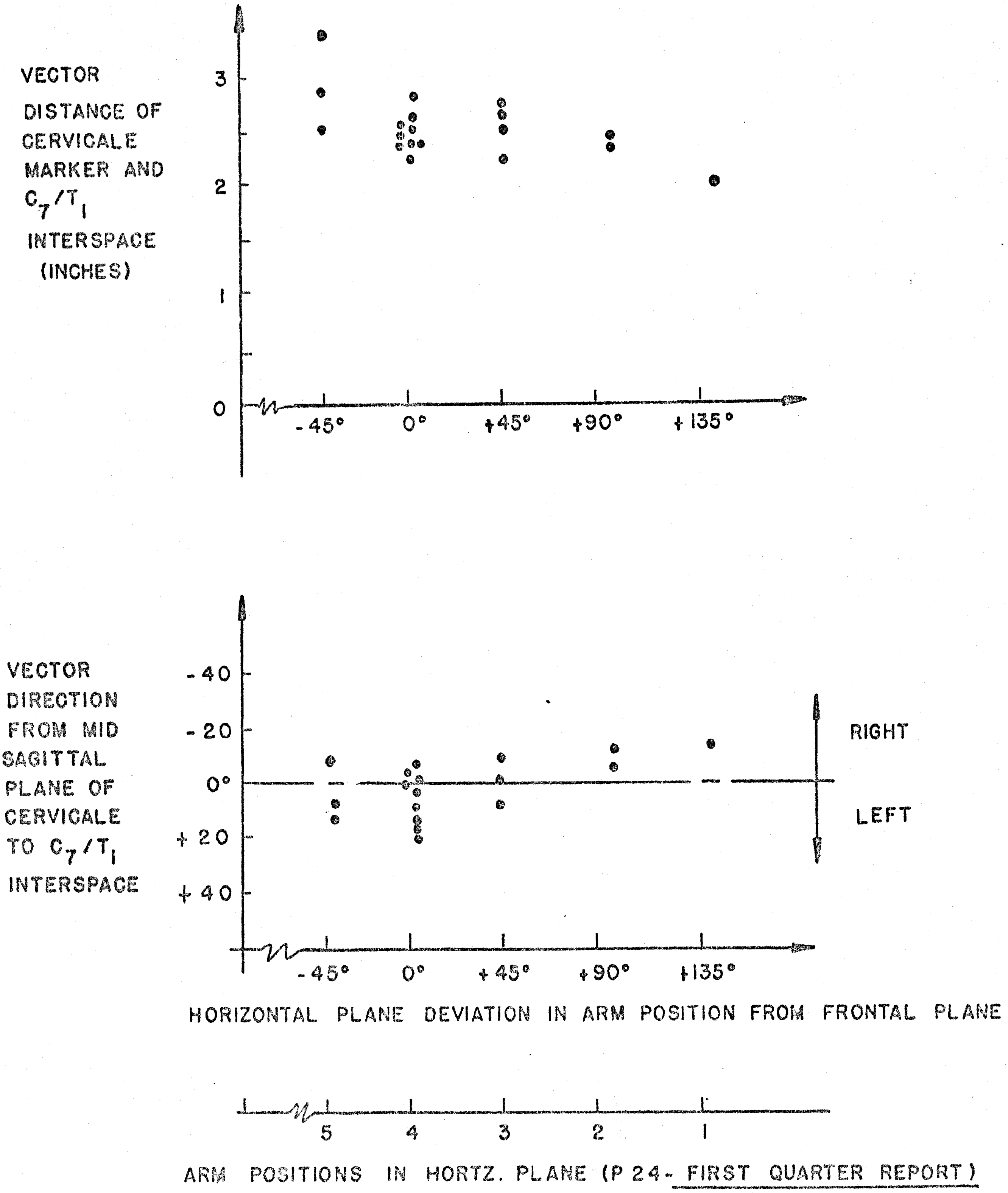


FIGURE 3

DATA FROM EIGHTEEN PAIRS OF OFF-SET SHOULDER X-RAYS DEPICTING SURFACE MARKER (CERVICALE) MOTION IN RESPECT TO C_7 / T_1 INTERSPACE

1) describe the torso external configurations for various arm positions in the seated or standing mode, and 2) update the existing "hard linkage" computer models of the torso to include a more comprehensive set of functional links of the torso.

A note on X-ray data sufficiency. As expected from the pilot X-ray studies described in the First Quarterly Report, the combination of relatively small body exposure areas and extremely variable tissue densities has resulted in a high loss of bone position data. It is now estimated that only approximately 60% of the bone data originally expected is available. These data are believed to be sufficient to model how the surface markers move relative to bone points, thus satisfying the objective of the X-ray studies, as presented in the First and Second Quarterly Reports. It is now clear, however, that sufficient X-ray bone position data have not been ascertained to alone provide a description of torso mobility. Thus the earlier decision to combine the X-rays with an extensive photogrammetric procedure is now well justified.

PHOTOGRAMMETRIC ANALYSIS TECHNIQUE

Both the four camera photogrammetry system and photoreduction system were described in the Second Quarterly Report. The purpose of this section is to describe and illustrate how the photogrammetric data is being analyzed and can be presented in the final report.

The photogrammetric study was iniated to determine how arm position affects the three-space positions of a selected set of surface markers on the torso. In particular, the study was designed to ascertain data as to how the complex is affected by various sub-maximal and near-maximal reaches. After reviewing all of the subject films, it has been estimated that sufficient data from two or more camera views is probably available to develope a good predictive model of the three-space coordinates of the following surface markers:

*Right acromion
*Left acromion
*Suprasternale
*C_7 spine marker-cervicale
*T_4 spine marker-cervicale
*T_8 spine marker-cervicale
*T_{12} spine marker-cervicale
*L_2 spine marker-cervicale
*L_5 spine marker-cervicale
*Right anterior superior illiac spine

The following neck and head marker positions will be modelled from the X-ray data, since head positions were not systematically manipulated in the photogrammetry studies:

*C_7 spine marker-cervicale
*Right tragion
*Left tragion
*Nasal root depression

This neck and head surface marker data will be combined with the neck bone center-of-rotation data to form a separate predictive model depicting the feasible positions for the nasion, as it relates to both cervicale (and thus C_7/T_1 interspace) and suprasternale positions. Graphs of the feasible nasion positions will be prepared for design reference.

The photogrammetric data of the surface markers previously listed for the trunk and shoulders will be analyzed by developing linear and non-linear regressions of the coordinates of each j th surface marker (X_j, Y_j, Z_j) on each of the selected elbow target coordinates (X_t, Y_t, Z_t) given in the Second Quarterly Report. This model does not include anthropometic variables, and hence it is referred to as a Population Model, and will be of the general form;

$$X_j = F_j\ (X_t,\ Y_t,\ Z_t)$$
$$Y_j = F_j\ (X_t,\ Y_t,\ Z_t)$$
$$Z_j = F_j\ (X_t,\ Y_t,\ Z_t)$$

A second predictive model will be developed which includes anthropometric variables. This model is referred to as the Anthropometric Model. The procedure for developing this model will involve:

1. Carrying out a review of the inter-correlation of each of the 67 anthropometric variables to determine a smaller set which can with stated and acceptable accuracy predict the other variables.
2. Selecting from the smaller set of anthropometric variables those that could be "anatomically possible influences" on the three-space coordinates of each surface marker.
3. Including these selected anthropometric variables in the multiple regressions to determine their influences on the prediction of a surface marker position, and selecting the most effective set S_j of the anthropmetric

variables, as described in the following.

Partial correlation coefficients will be used to determine which elements of the sets S_i are significant and the type of functional relationship to be used. Each of the anthropometric variables, a_{ij} in S_i, and transformations of those variables (such as L/a_{ij}, $\log(a_{ij})$ $e^{a_{ij}}$ and a_{ij}^2) will be correlated with the residuals of the Population Model. The resulting partial correlation coefficient matrix contains the same information that would be obtained if each variable, a_{ij}, and each non-linear transformation of the variables had been regressed separately on the residuals and tested for significance. The result of this procedure will be to reduce the feasible set S_i to a smaller set S_i^* of significant anthropometric variables. The set of variables S_i^* and the variables x_t, y_t and z_t will then be used as the independent variables in deriving the multiple regression model, referred to as the Anthropometric Model.

The result of this procedure will be an Anthropometric Model of the surface marker positions which will be of the form:

$$X_j = F_j\ (X_t\ ,\ Y_t,\ Z_t,\ S_j^*)$$
$$Y_j = F_j\ (X_t\ ,\ Y_t,\ Z_t,\ S_j^*)$$
$$Z_j = F_j\ (X_t\ ,\ Y_t\ \ Z_t\ \ S_j^*)$$

Technical Note: Goodness of Fit Tests. The measure of effectiveness to be used in judging the adequacy of the various models is the linear distance (R) between the predicted point $(\hat{x}_i, \hat{y}_i, \hat{z}_i)$ and the observed point (x_i, y_i, z_i). i.e.,

$$R = [\ (\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2 + (\hat{z}_i - z_i)^2]^{1/2}.$$

Such a procedure reduces the 3-dimensional variability to a one dimensional measure. In doing so it is being assumed that a deviation in the x direction is exactly as important as a deviation in the y direction. It is also assumed that the average deviation is the same and the deviations are uncorrelated in the x, y and z directions. The average linear deviation ($\bar{R}$) will be calculated for each subject, for the combined set of subjects, for the Population Model and for the Anthropometric Model. A comparison of these $\bar{R}$ will be used to assess the goodness of fit. Hence a designer would have a clear indication as to:

1. What degree of within-subject variation exists when a person repeatedly attempts to position his torso.
2. What prediction error exists when a general population is considered in total.
3. What prediction error is achieved if certain anthropometric values are considered.

Technical Note: Simultaneous Regression. Three simultaneous regression equations are used in all of the previously described models. This is in contrast to using a multivariate (vector) regression such as:

$$\Phi = \cdot \Theta$$

Where ϕ is the vector $(x_i, y_i, z_i)'$

B is the matrix of regression coefficients

Θ is the vector $(x_t, y_t, z_t, a_1, a_2, ---, a_n)'$

Theoretically the tests of hypothesis and the distribution theory are more rigorous for the multivariate model. However, for practical application the multivariate approach has numerous disadvantages. First, the computational procedures are several orders of magnitude more time consuming on the computer. Second, the real functional relationship between the dependent and independent variables is exaggerated. For example, biacromial breadth is functionally related to the x coordinate of the right acromion but has very insignificant influence on the z coordinate. However, in using the multivariate approach biacromial breadth will be regressed on the z coordinate of the acromion. Multivariate regression regresses all the variables in the vector of independent variables onto all the variables in the dependent variable vector. The (x_i, y_i, z_i) coordinates will be expressed as a function of 10 or more variables, but many of these variables are insignificant for two or more of the dependent variables. The third disadvantage of the multivariate approach is that the usual tests of hypotheses can not be interpreted. The tests are statistically very rigorous, but they have very little practical value. What does it mean to test the hypothesis that the matrix of regression coefficients equals a zero matrix? What are the practical implications of testing goodness of fit by comparing the variance-covariance matrix to a statistic derived from the Wishart distribution?

Graphical display of the movement pattern of the surface marks as a function of the movement of the elbow. Nine graphs will be derived for each of the ten anthropometric surface markers listed in the preceding. An example of the graphical presentation is the following for the right acromion.

1. the x coordinate of the right acromion versus the x coordinate of the elbow target.
2. the x coordinate of the right acromion versus the y coordinate of the elbow target
3. the x coordinate of the right acromion versus the z coordinate of the elbow target
4. the y coordinate of the right acromion versus the x coordinate of the elbow target
5. the y coordinate of the right acromion versus the y coordinate of the elbow target
6. the y coordinate of the right acromion versus the z coordinate of the elbow target
7. the z coordinate of the right acromion versus the x coordinate of the elbow target
8. the z coordinate of the right acromion versus the y coordinate of the elbow target
9. the z coordinate of the right acromion versus the z coordinate of the elbow target.

Example graphs are given in Figures 2, 4, 5 and 6 for the x coordinate of the acromion. There will be a total of 90 (9 x 10) graphs, conditional on the photogrammetric procedure being capable of generating sufficient data for

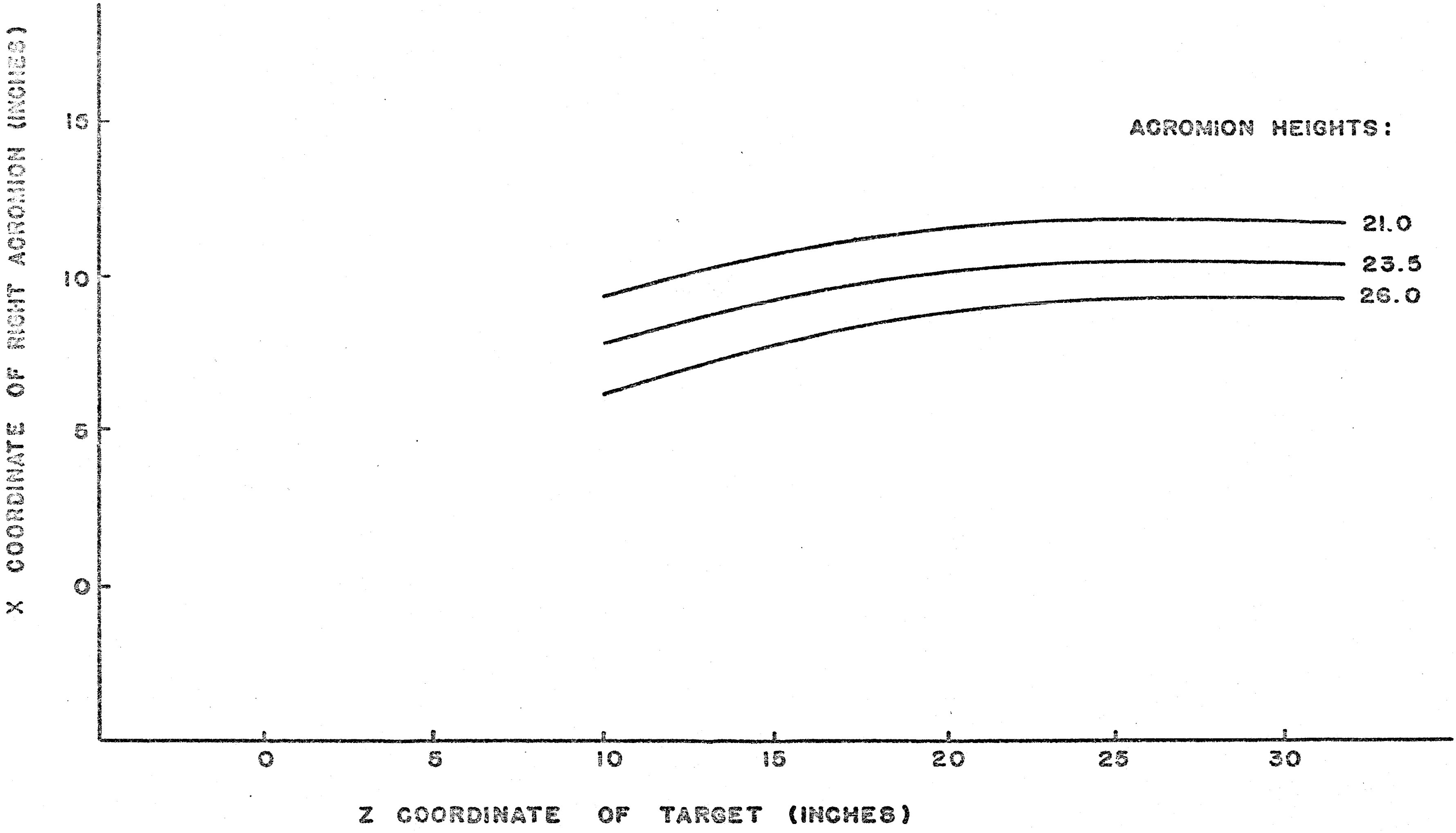


FIGURE 4

X COORDINATE OF RIGHT ACROMION vs. ELBOW Z COORDINATE

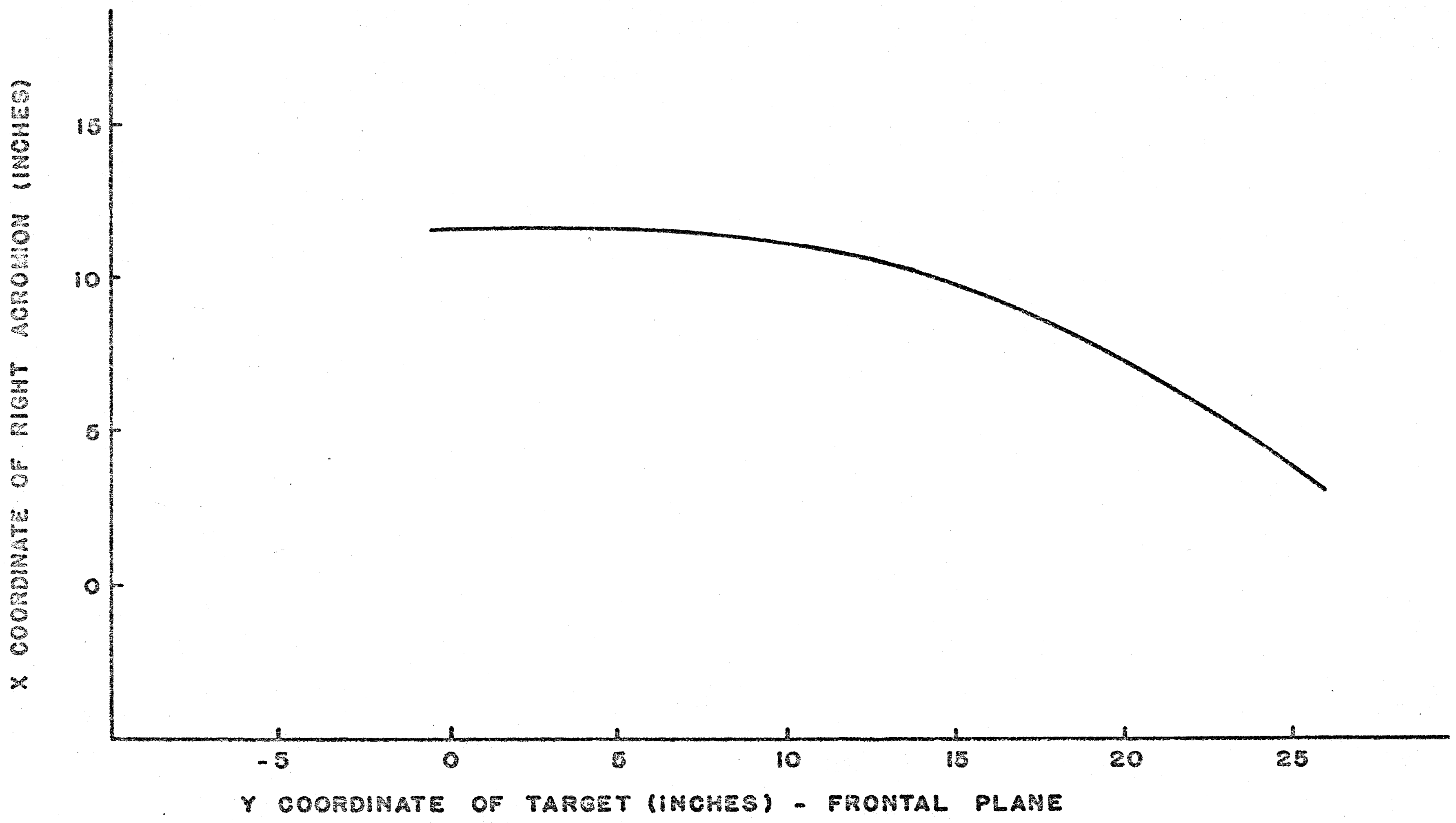


FIGURE 5

X COORDINATE OF RIGHT ACROMION vs. ELBOW Y COORDINATE

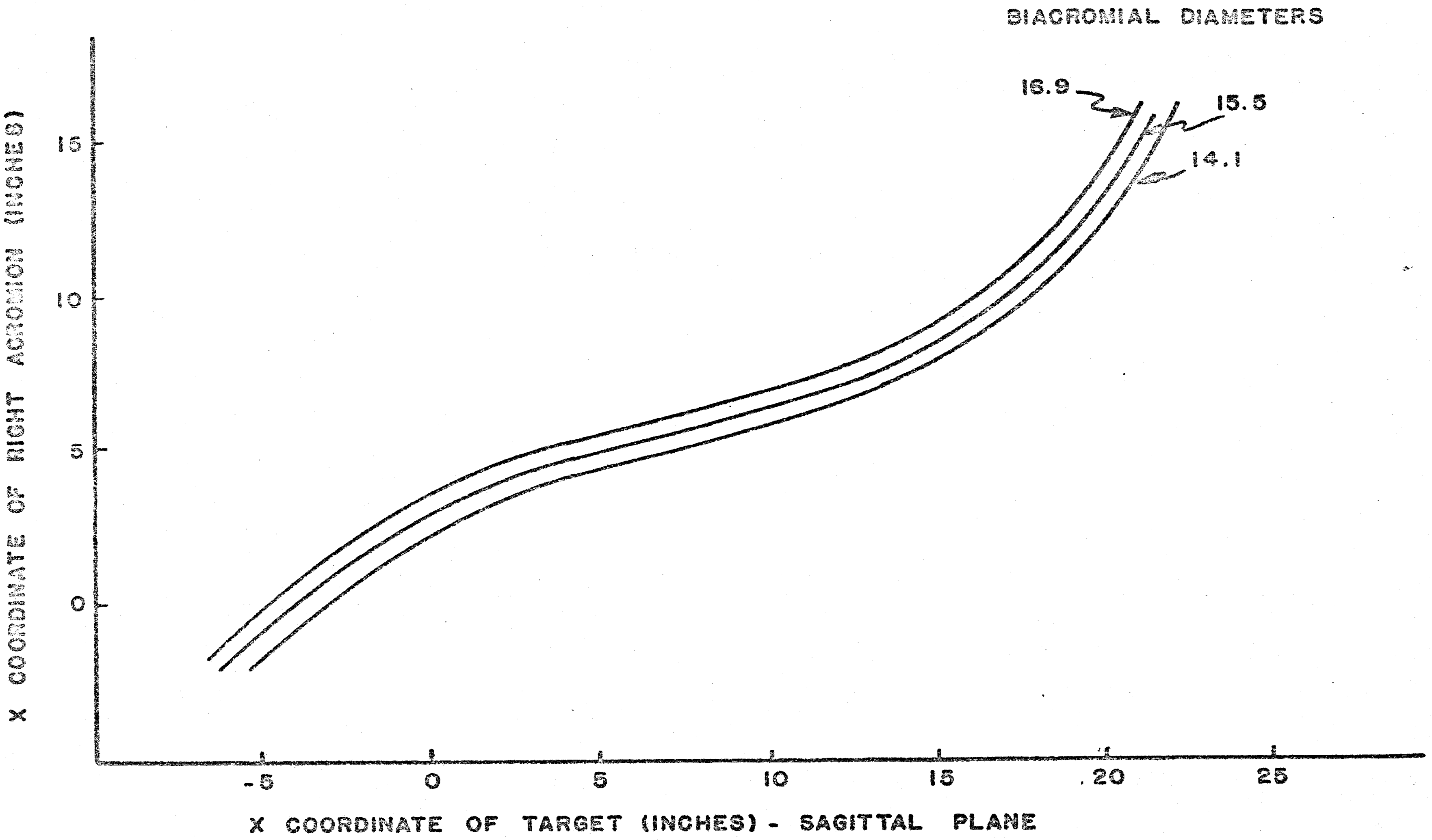


FIGURE 6

X COORDINATE OF RIGHT ACROMION vs. ELBOW X COORDINATE each of the surface landmarks.[1]

These graphs are invaluable in depicting the movement pattern of particular surface landmarks whose flow of movement can not be predicted on intuitive grounds. In cases where the general movement pattern can be anticipated, the use of the graphs are advantageous because they display the exact size of the movement deviate.

Reference Point Conversion Model. In performing the preceding analysis, the X_j, Y_j, Z_j coordinates for nine of the ten surface marks are being expressed in reference to L5 (the tenth mark). In other words, the coordinates given by the models and the graphs are based on a reference system which has its (0,0,0) point at the L5 spinal surface marker. This is in contrast to using a seat reference point at the intersection of the seat plane and the back plane of the chair as is often done. Such a

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[1] At present there is some doubt as to whether there will be sufficient data to model the suprasternale. The data from two subjects, as used to estimate the graphs in Figures 3, 4 and 5 and to verify the analysis procedure, have been completely analyzed. For these two subjects a large portion of the data for the suprasternale was lost. For a surface point to be recorded by the photogrammetric procedure, the body marker must be visible in at least two of the four cameras. In the case of the suprasternale, the marker is never visible in the rear camera and unfortunately it is usually blocked by the arm or the head in the side and top cameras. When the other subject films are read and coded, this problem should be reviewed with Mr. Kennedy, the Project Technical Monitor.

reference system makes the modelling completely dependent on the characteristics of the test chair. More important, the use of an L5 reference system allows the models to be extended to test conditions in which the subject is kneeling, leaning out of a chair, or standing on tip-toes. The intent has been to derive a "pure" self contained model of torso mobility, the input of which only requires knowledge of where the "bottom" of the torso and the elbow is in space.

Although the models are being derived for general use it is realized that the majority of applications will be for the seated or standing positions. Consequently, two reference point conversion models should be developed so that predicted torso positions can be referenced to a well described "normal" sitting or standing task.

Based on the coordinates of the elbow target and the anthropometry of the subject, the position of L5 will vary in reference to a seat or floor point. One of the required reference point conversion models will give the (x,y,z) coordinates of L5 with respect to a reference system whose (0,0,0) point is located where L5 would be if the subject was sitting normally in a non-exerting position in the hard chair described in the First Quarterly Report. A similar model will be derived for standing. The reference system for this model will be centered around where L5 would be if the subject were standing normally. The conversion models will have the form

$$d_x = f(x_t, y_t, z_t, a_1, a_2, - - -, a_n)$$
$$d_y = g(x_t, y_t, z_t, a_1, a_2, - - -, a_n)$$
$$d_z = h(x_t, y_t, z_t, a_1, a_2, - - -, a_n)$$

The d_x, d_y and d_z variables are the respective x, y and z correction factors to convert from an L5 reference system to an erect L5 reference system. For application, a test subject would be asked to sit or stand in the choosen environment and the x,y and z distances (d'_x, d'_y, d'_z) from L5 to the environmental reference point would be measured. Torso coordinates with respect to the environmental reference point are obtained by adding combined correction factors: $(d_x+d'_x)$, $(d_y+d'_y)$, and $(d_z+d'_z)$ to the (x,y,z) coordinates derived from the prediction models.

V. SUMMARY OF PROGRESS EXPECTED IN FOURTH QUARTER

It is expected that the fourth quarter work will result in completion of the data analysis, and will produce a first draft of the final report. Sepcifically this will entail the following:

1. Completion of all anthropometry, final tabulation, coding, and statistical analysis and correlation of data.
2. Evaluation of anthropometric techniques and limitations.
3. Review and evaluation of experimental anatomical dissection techniques and measurements initially employed with cadaver to determine accuracy of surface anthropometry and anatomical centers of joint motion through cineradiofluoroscopy.
4. Immediate reduction of the x-ray data from the cervical, thoracic, and lumbar/pelvic studies to both three-space coordinates and relative vector relationships between the surface and assumed bone centers-of-rotation.

5. Plots of the major surface-to-bone vectors for different strata of the population and different body positions.
6. Multiple regressions of the major surface-to-bone vectors to determine their expected values and variations, for both the population in general and for known anthropometrical strata.
7. Multiple regressions of the cervical neck extreme positions to determine the best predictor of the feasible nasion positions for given trunk positions.
8. Immediate finalization of the photographic coding, punching, and reduction of the data to three-space coordinates. It is expected that eleven subjects will supply acceptable films of data. As mentioned in the *Second Quarterly Report*, it was not thought possible to analyze all the data for each subject, but only about half was expected. Now it is believed possible to analyze all the data from those subjects whose films were acceptable for analysis, thus providing a total data set slightly larger than anticipated (almost 4000 surface marker positions in total).
9. Plots of the surface marker positions relative to the elbow target positions.
10. Multiple regressions of the surface marker data to determine their expected values and variances for both the population in general and for selected anthropometric variables.
11. Preparation of the final report draft.