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Bioengineering Study of Basic Physical Measurements Related to Susceptibility to Cervical Hyperextension-Hyperflexion

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BIOENGINEERING STUDY OF BASIC PHYSICAL MEASUREMENTS RELATED TO SUSCEPTIBILITY TO CERVICAL HYPEREXTENSION-HYPERFLEXION

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SUMMARY

During this initial reporting period our investigation has concentrated on an effort to establish the biostatistical design, literature survey and in-depth examination of previous studies and techniques, to define and design the techniques and methods to be utilized for anthropometry, radiography, electromyography, strength measurements, photometrics, and data analysis, to establish a subject pool, and to design, construct or order and test the experimental equipment. A brief summary of major task accomplishments to date reflect the following progress:

1. A literature search has revealed 1054 pertinent references which are attached and identified by five major subjects. A comparative analysis of the results of previous cervical motion studies has been tabulated.

2. A subject pool for the majority of the 18-24 year old subjects has been established, and consent and briefing forms have been designed. Medical screening is being accomplished by a medical history form and clinical examination of x-rays. Experience to date indicates that about 25% of volunteers have been eliminated for further tests on the basis of medical risk.

3. The biostatistical design of the experiment has been reanalyzed and found to be statistically valid.

4. Initial anthropometry descriptions and surface landmarks have been established.

5. The radiography laboratory and Picker x-ray equipment has been modified for this study, a soft and a hard seat constructed for initial comparative purposes, and seven subjects have had a complete cervical series taken and evaluated. Problems involving x-ray film size, subject positioning, and landmark analysis are being investigated.

6. The cervical measurement laboratory is nearly completed. Most equipment has been designed, constructed and installed, however several

critical items ordered have not been obtained. We have been successful in upgrading the necessary major equipment requirements, a recorder, by agreement to share costs between the College of Engineering and HSRI, and a 7-channel Ampex PR-500 FM tape recorder has been ordered. This allows us to stretch the $4500 budgeted for this item to obtain $8600 worth of equipment, which will considerably improve our data taking capability. The only delay to date from our scheduled projection may involve final delivery of this item, involving mutual University of Michigan and I.I.H.S. agreement relative to disposition and delivery time. Arrangements are being made to attempt to obtain similar equipment on temporary loan.

7. Initial mathematical modeling studies have been completed and results indicate the following conclusions:

a. Neck muscle strength has been isolated as an important variable affecting head-neck kinematics and dynamics. Because of this, muscle response time should be considered important in the measurement program.

b. The strength of neck motion limiting structures has also been isolated as an important variable. Although outside the scope of the current project, it is possible that these quantities could be estimated using cadaver material.

c. The range of motion of the neck in extension has been found to influence the maximum angulation occurring during impact and, as such, is an important quantity to be determined, particularly from the x-ray studies.

d. The weight of the head and the location of its center of gravity have both been found to influence the angulation of the head with respect to the torso. The effect of this is to increase the forces which must be exerted by the neck musculature to restrict head motion during impact.

e. The moment of inertia of the head exerts an influence considerably smaller than that exerted by mass or center of gravity.

f. Differences in the kinematics and dynamics of a small woman compared with a large man are more likely to be related to strength properties of the musculature and joints as well as the way the forces are distributed over the body than to body size alone.

8. Three different data analysis programs will be used in addition to the mathematical modeling. These involve the Hewlett-Packard 2115-A computer for photogrammetry and analog signal analysis, and the University of Michigan IBM 360-67 Computer System for statistical analysis of anthropometry and test results.

I. INTRODUCTION

Rear-end collisions commonly result in neck injury to the occupants. However recent field and clinical investigations indicate that there is a significant preponderance of "whiplash" symptoms among females. Little information is known concerning variation in head mass or center of gravity of the seated occupant or variation of neck muscle strength as related to age, sex, and physique differences, and no previous study has related variation in neck muscle response time to external acceleration stimulus. Such information would appear to be of basic importance in consideration of sensitivity to hyperextension-hyperflexion injury.

The primary objective of this study is to determine the range of physical variation in function and structure of the human neck, with variables of age, sex, and stature, as a basis for improved head protection design in vehicular occupant hyperextension-hyperflexion accidents. Specific tests and measurements are being designed and will be conducted to result in five major types of information relating to the range of physical and sexual variation of the neck in a representative U.S. population. Neck measurements to be determined include anthropometry, muscle strength, voluntary range of extension and flexion cervical motion, and muscle response time. Mathematical modeling will be used to predict dynamic sensitivity to changes in the parameters developed.

The following informal technical progress report provides a brief review of the initial 90-day period of this investigation. The status of accomplishments to date reflect the preliminary work necessary to undertake the subject measurements. Emphasis has been placed upon design and construction of the necessary equipment, establishment of procedures, and preparations for the tests. Some preliminary testing of subjects has suggested modifications and changes to techniques and protocol which will enhance the overall program, and further refinement will probably continue with the initial series.

II. TASK PROGRESS

1. Literature Survey

There appears to be a voluminous body of literature related to the neck, although the majority of papers pertain to clinical aspects of trauma and treatment. During this initial period we have concentrated on not only locating references but also retrieval of each paper, and have obtained copies of many of the papers listed to date. The 1054 references located so far are attached in the Bibliography in Appendix I. At this point they have been divided into five general categories; motion/mobility, mechanisms of injury, injuries/fractures, anatomy/radiography, and experimental strength and stress. Due to the bulk of these it seems likely that we will further categorize for more efficient utilization.

So far we have found 18 different studies of "normal" cervical motion, as summarized in Table I. Many other motion studies in the literature were not considered because they utilized subjects with previous history of neck injury and could generate abnormal motion readings. Only two studies found in the "normal motion" literature use both male and female subjects over a wide age span, while the rest report measurements based upon a single sex, a limited age range and a selected sample.

It is difficult to compare results because of the different techniques, measurements, and end-points employed by the various investigators. Extensions and flexion limits have only been identified in ten studies although all studies listed a range of motion measured in the sagittal plane alone. Combining the 1754 total subjects for all previous studies identified to date, results in a mean range of sagittal motion of 129°. But it is obvious from examination of previous work that no thorough study of the basic parameters outlined in this investigation have been conducted for a large number of subjects representative of the general population and including both sexes for a wide age-span. These data provide additional confidence in the basis for our initial proposal.

2. Biostatistical Design Considerations

At this time no further statistical data have been gathered to change the design of the population survey. In other words, there is no prior reason for decreasing or increasing the cell sizes for each population stratification. Because data of others may be disclosed at a later date; however, the population survey will be conducted in two phases. First, all cells will be filled with a minimum of 10 subjects. An analysis of variance[1] will be conducted on these data to determine the linearity of the effects of age and stature in both sexes for each of the various dependent random variables. The dependent variables which can be measured are:

*Cervical (neutral position) Flexion and Extension Isometric Strengths

*Cervical Flexion and Extension Volitional Range-of-Motion

*Geometric Configuration of Cervical Neck Vertebrae for Neutral and Extreme Positions

*Cervical Flexor and Extensor Neural Stretch Reflex Times to a Controlled Neck Jerk

*Cervical Flexion and Extension Acceleration Responses

*Cervical Anthropometric Dimensions to a Controlled Neck Jerk

If from the first phase analyses of data it is found that some specific cells have data that significantly deviate from either linear effects in the independent variables, or an effect which cannot be explained based on

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[1]The data will be tested for Normality (Kolomogorov-Smirnov Test), and constant cell variances (Chi-Square Test), before performing the analysis of variance. Appropriate transformations of the data will be invoked depending on the results of these tests.

TABLE I
A SUMMARY OF PREVIOUS CERVICAL MOTION STUDIES IDENTIFIED TO DATE

	Sex	N	Age	Flexion°	Extension°	Total°	Lateral Flexion°	Rotation°	Comments
1) Ferlic	M	31	15-24			133°	80°	147°	
Ferlic	M	34	25-34			129°	76°	143°	
Ferlic	M	22	35-44			115°	62°	132°	
Ferlic	M	5	45-54			120°	63°	138°	
Ferlic	M	10	55-64			117°	64°	125°	
Ferlic	M	3	65-74			101°	43°	101°	
2) Delahaye	M	198	23($\bar{x}$)	72.2°	39.4°	111.6°			
3) Beal	M	1	34			135°			
4) Kottke	M	87	15-30	50°	45°	95°(117°)			* 22° added - incomplete measurement
5) Buck	M	47	18-23	66°	73°	139°		146°	
6) Glanville	M	10	20-40	59.8°	61.2°	121°			
7) Defibaugh	M	30	24-40	58°	79°	137°	91°	168°	
8) Leighton (55)	M	40	16			121.9°	78.6°	157.3°	
9) Leighton (57)	M	50				147.2°	115.3°	185.3°	College swimmers
Leighton (57)	M	100				142.3°	109.2°	185°	College Baseball Players
Leighton (57)	M	100				143.7°	99.8°	187.8°	College Basketball Players
Leighton (57	M	44				137.5°	108.7°	182.2°	College Shot Putters
10) Leighton (56)	M	100	10			126°	97°	177°	
Leighton (56)	M	50	12			138°	97°	162°	
Leighton (56)	M	100	14			131°	92°	159°	
Leighton (56)	M	100	18			127°	98°	159°	
11) Leighton (57)	M	50	16			123.4°	88.4°	158.4°	
Leighton (57)	M	5	25-46			129.6°	98°	181°	Weight Lifters
Leighton (57)	M	11				141.8°	115.9°	160.2°	College Gymnasts
Leighton (57)	M	9				130°	111°	151°	Wrestlers
12) Hupprich	F	50	6			124.3°		168.5°	
Hupprich	F	50	9			127.7°		174.1°	
Hupprich	F	50	12			134.9°		170.4°	
Hupprich	F	50	15			125.4°		157.3°	
Hupprich	F	100	18			119.4°		163.2°	
13) Bhalla	F	20	18-23	58°	34°	92°(125°)*			* Measurements began at c 2/3 - 33° added to compensate
5) Buck	F	53	18-23	69°	81°	150°		147°	
14) Bennett	F	50	18-24	54.4°	93.2°	147.6°		151°	Subjects urged to achieve maximum measurement
1) Ferlic	F	34	15-24			148°	82°	154°	
Ferlic	F	25	25-34			129°	72°	141°	
Ferlic	F	16	35-44			121°	74°	141°	
Ferlic	F	10	45-54			115°	71°	138°	
Ferlic	F	6	55-64			115°	61°	133°	
Ferlic	F	3	65-74			123°	70°	130°	
15) Bakke	M/F	31	3-79	32°	70°	102°(124°)*			* Measurements began at c 1/2 - 22° added to compensate
16) Batch				40°	50°	90°	80°	110°	
17) Llopis Faner						114°(136°)*			* Measurements began at c 1/2 - 22° added to compensate
18) Aho	M/F	15	16-30			108°(130°)*			

7

other published data, then the remaining sampling will be biased to include more than two subjects in each of the questionable cells. This flexibility in the design will allow a "retest" of the important first phase results, thus serving as a complimentary evaluation which will give added inferential power to the total results.

Thus the population sample will resemble the layout in Table II.

TABLE II.

REVISED POPULATION SAMPLE (PHASE ONE)

Percentile Stature	SEX					
	Male (ages)			Female (ages)		
	18-24	35-44	65-74	18-24	35-44	65-74
1 - 20%	10	10	10	10	10	10
40 - 60%	10	10	10	10	10	10
80 - 99%	10	10	10	10	10	10

The proposed 36 remaining subjects would be selected based upon results of analysis of the above 180 subject data.

It should also be noted that if there is enough variability in other secondary population data (e.g., race, health, or occupational factors), or within the dependent variables, co-factor analyses will be performed to determine the magnitude of any possible statistical correlations.

3. Subject Pool

One initial objective of this study was to establish a volunteer subject pool, based upon the primary experimental design factors of sex, age, and stature. This has progressed better than expected, and most of the necessary number of subjects for the 18 through 24 year age group have now been recruited. We have started with this age group first because they are easiest to obtain, and are more flexible regarding time constraints. However, it is also apparent that the initial subjects will require more time, and as techniques and procedures are replicated for subsequent subjects measurements will be more efficiently taken in less time.

After numerous revisions, and discussions with Dr. Portnoy, our neurosurgical consultant, and Dr. Baum and Dr. Threatt, our Radiology consultants, a brief health questionnaire has evolved. The Health questionnaire as well as initial instructions and a subject consent form follow in Figures 1 - 3. It was originally based upon the Cornell Medical Index for the R.I.W.V. multiphasic testing, but has been considerably shortened and modified to include questions specific to this study. It is used as the initial stage of medical screening of subjects. Each subject volunteering for the study first fills out this form, which is reviewed by Dr. Baum or Dr. Threatt. If, in their judgment, the subject has indicated no previous medical history which could suggest a medical risk in tests which he would be expected to undergo in this investigation he is allowed to proceed to the radiography. Several subjects to date have been disqualified on the basis of their responses to the health questionnaire.

The second level of medical screening involves examination of the subject's x-ray films, again by Dr. Baum or Dr. Threatt, to determine if there is abnormality, degenerative bone disease, or evidence of previous trauma which might make further testing a hazard to the subject's health. The subject is also measured prior to taking the radiographs to insure that his (or her) height is within the selected range requirements.

At present there are thus three stages to subject selection and testing: (1) the volunteer is located (based upon experimental design criteria) and asked to fill out the health questionnaire; (2) if he passes initial medical screening he then is measured for stature and has a set of five x-rays taken; (3) after successful medical screening of the x-rays the subject subsequently participates in the remainder of the tests. We are attempting to maintain rigid clinical controls for the protection of the subject, and he is not allowed to take part in the tests until our medical colleagues are satisfied on the basis of both his medical history and cervical x-ray films. We also plan to carefully document the actual loads and motions that the subject is exposed to in the strength tests by use of a high speed rapid sequence Polaroid camera, which will instantaneously provide eight sequential motion frames on a single exposure. Such documentation could be of important medico-legal significance should some subject decide subsequent to this test that he had incurred any trauma.

We presently have an adequate number of subjects for the next few months, but anticipate that older subjects will be more difficult to obtain. We also recognize that for the older extremes it will be difficult to find subjects without degenerative bone disease and, to be more representative, we may have to reassess the medical screening procedures established.

Figure 1. Initial Letter Sent to Subjects

Dear Subject:

Enclosed is a brief medical questionnaire which will serve as a preliminary screening for our study on neck responses. The study in which you are being considered as a candidate is being conducted for the Insurance Institute for Highway Safety by The University of Michigan, Industrial Engineering Department and Highway Safety Research Institute. All data will be coded so that your individual identity is protected.

The purpose of the study is to determine information on various neck parameters such as size, strength, range of motion, etc. From these data we can design improvements to better protect people in automobile accidents.

The procedure will involve two sessions. In the first examination several x-rays of your neck will be taken. (Time involved about 1 hour.) Those of you qualified will be contacted to come to a second series of measurements, photographs, and tests requiring about 3 hours. Since at this time we are uncertain as to whether you will be involved in the complete series, we have included only a brief sketch of the procedures. Upon initiation into the formal testing a full description will be given.

Once you are accepted as a subject, you will receive monetary compensation for your time given to the study. If at any time during the tests you feel uncomfortable or wish to terminate as a subject you will be free to do so and will be compensated for the time you have given. The scheduling of tests will be arranged at your convenience and transportation can be provided for those who need it. The tests will take place at the Highway Safety Research Institute located on North Campus.

Please fill in the questionnaire with care and return it as quickly as possible to:

Lauretta MacColman
Highway Safety Research Institute
Biomedical Department
Room 424
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105

You will be contacted soon after we have received the completed questionnaire to arrange x-ray scheduling.

Sincerely,

Richard G. Snyder, Ph.D.
Head, Biomedical Department
HSRI
Principal Investigator

Janet Baum, M.D.
Resident in Radiology
University Hospital

Figure 2. Health Questionnaire Form for Initial Medical Screening of Subjects.

HEALTH QUESTIONNAIRE

Print Your Name ______________________ Date __________ Telephone No. ______________

Your Home Address ____ Soc. Sec. No. __________
Number Street City

Usual Type of Work ______________________________________ Birthdate __________

Height __________ Weight __________ Subject No. __________

DIRECTIONS: Answer all questions. If you are uncertain as to how to best answer a question please mark a Yes or No and explain further either at space provided after question or at the end of the questionnaire with the letter and number marked.

1. Do you have a drivers license? .... Yes No

   How many miles do you drive a year approximately __________

2. Has your eyesight changed recently? .... Yes No
3. Do you hear ringing or buzzing in your ears? .... Yes No
4. Do you have severe pains in your chest? .... Yes No

   If yes, explain __________

   ____

5. Do you get short of breath long before anyone else? .... Yes No

   If yes, explain __________

   ____

6. Have you lost more than 10 pounds in the past 3 months? .... Yes No
7. Do you have severe pains in your abdomen (stomach)? .... Yes No
8. Did a doctor ever say you had diabetes (sugar in blood and urine)? .... Yes No
9. Does severe rheumatism (or arthritis) interfere with your work? .... Yes No
10. Are you now under a doctor's care? Yes No

   If yes, doctor's name and address

   ____

   ____

A

1. Do you need glasses for readigg or other close work? .... Yes No
2. Do you need glasses for seeing things at a distance? .... Yes No
3. Has your eyesight ever blacked out completely? .... Yes No
4. Do you ever see things double or blurred? .. Yes No
5. Do your eyes continually blink or water? .. Yes No
6. Do you ever have severe pains in or behind your eyes? .... Yes No
7. Do you often see spots before your eyes? .. Yes No
8. Are your eyes often red or inflamed? ...... Yes No
9. Are you hard of hearing? .... Yes No
10. Have you had frequent severe ear aches? ... Yes No
11. Have you ever had a running ear? .... Yes No

B

1. Have you ever been hoarse for more than a month? .... Yes No
2. Have you ever had frequent or severe nose bleeds? .... Yes No
3. Have you had any x-rays, especially a chest x-ray? .... Yes No

   If yes, when __________

4. Did your chest x-ray show anything wrong in your chest? .... Yes No

(Modified from the Cornell Medical Index for the R.I.W.U. multiphasic testing, June 1951)

Print Your Name ______________________________ Subject No. ____________

5. Were you ever in an atuomobile accident where you might have suffered "whiplash" or neck injury? .... Yes No

C

1. Has a doctor ever said you blood pressure was too high or too low? .... Yes No

2. Does your heart often beat very rapidly? .... Yes No

   If yes, explain ______________________

3. Do you ever have difficulty in getting your breath? .... Yes No

D

1. Do you have any difficulty in swallowing? .... Yes No

2. Are you often sick to your stomach with vomiting? .... Yes No

3. Do you often have indigestion? .... Yes No

   If yes, explain ______________________

E

1. Have your joints ever been painfully swollen? .... Yes No

   If yes, explain ______________________

2. Do your muscles and joints always feel stiff? .... Yes No

   If yes, explain ______________________

3. Do you usually have severe pains in the arms or legs? .... Yes No

   If yes, explain ______________________

4. Are you crippled with severe rheumatism (or arthritis)? .... Yes No

   If yes, explain ______________________

5. Does rheumatism run in your faimily ? ... Yes No

   If yes, explain ______________________

6. Do you suffer from weak or painful feet? .... Yes No

7. Do you have pains in the back or neck that make it hard for you to keep up with your daily activities? .... Yes No

   If yes, explain ______________________

8. Are you troubled by a serious bodily disability or deformity? .... Yes No

   If yes, explain ______________________

F

1. Do you have frequent severe headaches? .... Yes No

2. Do you often have spells of severe dizziness? ... Yes No

3. Have you fainted more than twice in your life? .... Yes No

   If yes, explain ______________________

4. Are you ever aware of numbness or tingling in any part of your body? .... Yes No

   If yes, explain ______________________

5. Was any part of your body ever paralyzed? .... Yes No

   If yes, explain ______________________

6. Were you ever knocked unconscious? .... Yes No

   If yes, explain ______________________

7. Have you ever noticed a twitching of any part of your body? (other than eyes) .... Yes No

   If yes, explain ______________________

8. Did you ever have a convulsion (epilepsy)? .... Yes No

9. Has anyone in your family ever had convulsions (epilepsy)? .... Yes No

G

1. Are you definitely overweight? .... Yes No

2. Are you definitely underweight? .... Yes No

3. Has there been any recent change in your weight? .... Yes No

Print Your Name ______________________ Subject No. __________

4. Have you ever had a serious operation? .... Yes No
If yes, explain ______________________

5. Have you ever had a serious injury? .... Yes No

If yes, explain ______________________

6. Do you often have small accidents
or injuries? .... Yes No

If yes, explain ______________________

H

1. Are you considered a nervous person? .... Yes No

Additional Comments: (Please include dates, symptoms, frequency of occurrence, and any other relevant data.)

Figure 3. Subject Consent Form

SUBJECT CONSENT FORM

I, the undersigned, understand that the purpose of this study is to determine basic information on the human neck necessary for improved protection of the occupant in automotive accidents. Specific tests in which I will be asked to be a subject include anthropometric measurements, neck muscle strength, voluntary range of motion, and variation in muscle response time. I acknowledge that I have received a complete briefing of these tests, am satisfied that I understand what is involved, and consent to any hazards involved. I have completed the health questionnaire, and am aware that my participation will be subject to medical screening both as to any history or subsequent x-ray findings which might make it inadvisable for me to continue. I realize that some discomfort or muscle strains could result from my participation, although the experimental procedures and apparatus have been designed to minimize these hazards. I also understand that I will be allowed, at any time, to stop for rest or to discontinue my participation in this study without prejudice or change in my pay. I further acknowledge that all the data are confidential and I agree to allow publication of any or all of the data collected on this data if presented in a coded form not identifying me.

Signature of Subject   Date

Signature of Witness   Date

4. Anthropometry

Stature is one of the three primary factors of subject selection and we have been taking this measurement on all subjects at the time of their initial x-ray screening (Table III). Since some subjects may not be medically accepted for subsequent tests, the balance of the anthropometry on each subject was scheduled to be taken when they report for the cervical tests. At the present time we are reconsidering this scheduling and may do all anthropometry when initial x-rays are taken.

There has been much consideration of the specific anthropometric measurements necessary, and the appended list in Table IV indicates the measurements selected to date. Only three are taken in the standing position, and some 32 are taken in the seated position. This list is heavily weighted with additional head measurements, which is believed to be justified from the results of the mathematical modeling which concluded that head weight and location of its center of gravity both affect the dynamics angulation of the head with respect to the torso.

Listed in part C of Table IV are eight additional measurements necessary if skinfold (fat) measures are to be obtained. These measures are used as an assessment of body physique after the Heath-Carter technique (Heath and Carter, 1969), which allows a universal rating scale and criteria applicable to both sexes at all ages. The difficulty is that many of these measures cannot be taken unless the subject is partially disrobed and we are uncertain as to whether this will create problems with the older subjects. We previously have had no difficulty in taking such measurements on both male and female subjects (Snyder et al, 1971; Schanne, 1972) in the younger age bracket.

TABLE III.

SUBJECT SELECTION*

MALES	AGE	STATURE	PERCENTILES
10	18 - 24	62.6 to 66.5"	(1-20 %ile)
10		67.9 to 69.3"	(40-60 %ile)
10		70.9 to 74.8"	(80-99 %ile)
10	35 - 44	62.3 to 66.4"	(1-20 %ile)
10		68.1 to 69.2"	(40-60 %ile)
10		70.7 to 74.1"	(80-99 %ile)
10	65 - 74	60.8 to 64.8"	(1-20 %ile)
10		66.2 to 67.5"	(40-60 %ile)
10		68.9 to 72.0"	(80-99 %ile)
FEMALES			
10	18 - 24	58.4 to 61.6"	(1-20 %ile)
10		63.0 to 64.5"	(40-60 %ile)
10		65.9 to 69.3"	(80-99 %ile)
10	35 - 44	57.6 to 61.4"	(1-20 %ile)
10		62.8 to 64.1"	(40-60 %ile)
10		65.5 to 69.0"	(80-99 %ile)
10	65 - 74	55.8 to 59.5"	(1-20 %ile)
10		61.1 to 62.1"	(40-60 %ile)
10		63.7 to 67.0"	(80-90 %ile)

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*Based upon U.S. Department of Health, Education and Welfare "Weight, Height, and Selected Body Dimensions of Adults. United States - 1960-1962. National Center for Health Statistics No. 1000. Series 11. Number 8. Table 2, p. 27.

TABLE IV.
ANTHROPOMETRY

A. STANDING

1. Weight
2. Stature
3. Cervicale (C_7)

B. SEATED

1. Sitting Height (slumped)
2. Sitting Eye Height (slumped)
3. Sitting Height (erect)
4. Sitting Eye Height (erect)
5. Sitting Cervicale Height
6. Sitting Suprasternale Height
7. Nasal Root Depression
8. Right Tragion
9. Left Tragion
10. Sitting Right Shoulder (acromion) Height
11. Sitting Left Shoulder (acromion) Height
12. Biacromial Breadth
13. Shoulder Breadth (Bideltoid)
14. Anterior Neck Length
15. Posterior Neck Length
16. Lateral Neck Breadth (mid)
17. Anterior-Posterior Neck Breadth (mid)
18. Superior Neck Circumference
19. Inferior Neck Circumference
20. Head Circumference
21. Head Ellipse Circumference (Bennett)
22. Head Breadth
23. Head Length
24. Head Height
25. Sagittal Arc
26. Coronal Arc
27. Bitragion Diameter
28. Minimum Frontal Diameter
29. Minimum Frontal Arc
30. Bitragion Minimum Frontal Arc
31. Bitragion Inion Arc
32. Posterior Arc

C. SKINFOLD (Fat) MEASURES

1. Biceps Flexed Circumference (right)
2. Calf Circumference (right)
3. Femoral Biepicondylar Diameter (right)
4. Humerus Biepicondylar Diameter (right)
5. Right Triceps Skinfold
6. Right Subscapular Skinfold
7. Right Suprailiac Skinfold
8. Right Posterior Mid-Calf

D. CALCULATIONS

1. Angle of Shoulder Slope
2. Moments of Inertia
3. Head Center of Gravity
4. Head Weight/Mass

ADDITIONAL ANTHROPOMETRY

(To be considered. Problem involves most require minimum clothing to obtain and additional subject problem.)

1. Seated Hip Breadth
2. Seated Height of Right Anterior Iliac Spine
3. Seat Surface - Trochanterion (vertical, seated)
4. Seat Back - Trochanterion (horizontal, seated)
5. Sitting Knee Height
6. Sitting Knee Height (maximum clearance)
7. Buttock-Knee Length
8. Chin-Neck Intersect

Similarly, it would be desirable to obtain certain measurements which, while not essential for this study, would allow specific comparison with other populations. Some of these are also listed in Table IV and are currently under consideration.

In the past it has been found essential to have a clear definition of the specific technique for each anatomical landmark to be measured, since there are many significant differences in definitions for the same landmark. A start has been made, as indicated in Table V, to provide specific descriptions of each landmark. These descriptions will be refined and a final list completed prior to initiating Phase II measurement of subjects in April. Since Mrs. MacColman is responsible for subject selection and taking the x-rays, she will also be trained in taking the anthropometry. It is desirable to have a single investigator take all measurements to avoid inter-measurer errors.

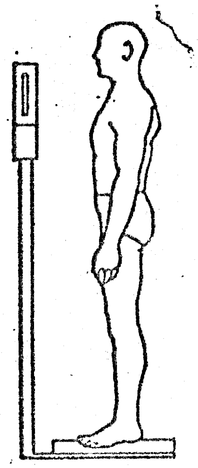
Radiographic markers have been placed in several locations in the initial subjects. Locations at the temporomandibular joint, C_2, and inion have been eliminated. At present those located at nasion and tragion cannot be visualized adequately due to the present x-ray film size. Probable radiographic and photometric markers are shown in Table VI.

TABLE V.

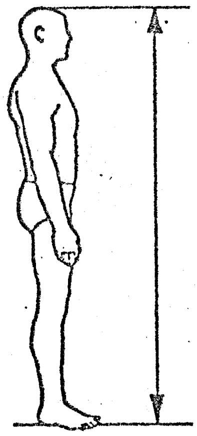
DESCRIPTION OF ANTHROPOMETRIC DIMENSIONS

A. Subject in Standing Position:

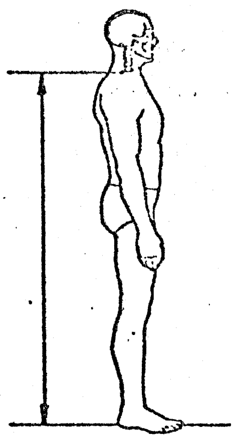
1. WEIGHT - Taken on standard medical type scale to nearest one-half pound. Subject unclothed except for shorts (plus halter for women).



2. STATURE - The subject maintains an erect standing posture, feet together, arms hanging at his side, looking straight ahead with head held in the Frankfurt Plane,* which is determined by lining up the infraorbital margins with tragion in the same horizontal plane. The vertical distance is measured with the anthropometer from the floor to the highest point on the subject's head with the anthropometer arm firmly contacting the scalp.

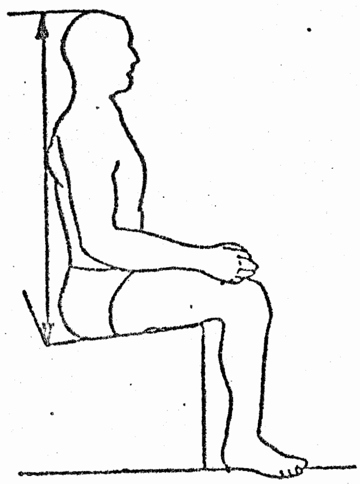


3. CERVICALE - The subject maintains an erect posture, feet together, arms hanging at his side, looking straight ahead with head held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the floor to the palpable spinous process of the seventh cervical vertebra.



*Frankfurt Plane or horizontal (F.H.). The plane determined by the points on the infraorbital margins and the tragion.

B. Subject in Seated Position:



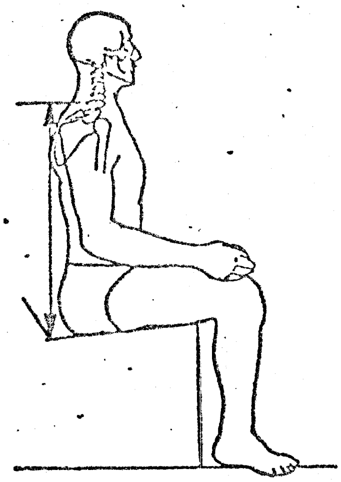
1. SITTING HEIGHT (slumped) - The seated subject is allowed to assume normal slumped sitting position, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The vertical distance is measured from the sitting surface to top of head (vertex).

2. SITTING EYE HEIGHT (slumped) - The seated subject is allowed to assume normal slumped sitting position, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The vertical distance is measured from the sitting surface to the inner corner (internal canthus) of the right eye.

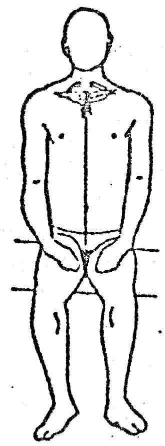
3. SITTING HEIGHT (erect) - The subject sits erect with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The head is held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the sitting surface to vertex with the anthropometer arm firmly touching the scalp..

4. SITTING EYE HEIGHT (erect) - The subject sits erect, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The head is held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the sitting surface to the inner corner (internal canthus) of the right eye.

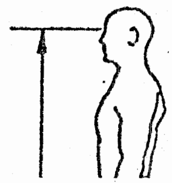
5. SITTING CERVICALE HEIGHT - The subject sits erect, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The head is held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the sitting surface to the palpable spinous process of the seventh cervical vertebra.



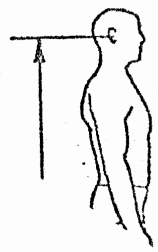
6. SITTING SUPRASTERNALE HEIGHT - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. Facing the subject, the vertical distance is measured with an anthropometer from the sitting surface to the superior margin of the jugular notch of the manubrium.



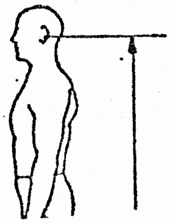
7. NASAL ROOT DEPRESSION - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. Facing the subject, the vertical distance is measured with an anthropometer from the sitting surface to the point of greatest indentation where the bridge of the nose joins the supraorbital ridge of the forehead.



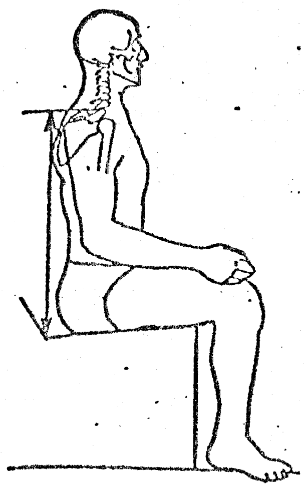
8. RIGHT TRAGION - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. The vertical distance is measured with an anthropometer on the right side of the subject from the sitting surface to the anterior limit of the cartilaginous notch superior to the tragus of the right ear.



9. LEFT TRAGION - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. The vertical distance is measured with an anthropometer on the left side of the subject from the sitting surface to the anterior limit of the cartilaginous notch superior to the tragus of the left ear.

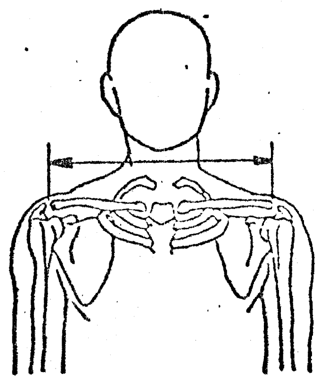


10. <u>SITTING RIGHT SHOULDER</u> - (acromion) HEIGHT - The subject maintains an erect posture, with arms hanging at sides and resting on upper legs, feet together and resting on a surface so that the knees are bent at about right angles. The vertical distance is measured from behind the subject using an anthropometer from the sitting surface to the superior lateral border palpable on the margin of the acromion process of the right scapula (acromion).



11. <u>SITTING LEFT SHOULDER</u> (acromion) HEIGHT - The subject maintains an erect posture, with arms hanging at side and resting on upper legs, feet together and resting on a surface so that the knees are bent at about right angles. The vertical distance is measured from behind the subject using an anthropometer from the sitting surface to the superior lateral border palpable on the margin of the acromion process of the left scapula (acromion).

12. <u>BIACROMIAL BREADTH</u> - The subject maintains an erect posture, with arms hanging at side and resting on upper legs, looking straight ahead. Facing the subject, the horizontal distance is measured with an anthropometer between the superior lateral border of the acromial processes of the left and right scapula.



13. <u>SHOULDER BREADTH (Bideltoid)</u> - The subject sits erect, his upper arms hanging at his sides, and his forearms extended horizontally. Using the anthropometer, the distance is measured horizontally across the maximum lateral protrusion of the deltoid muscles.

14. <u>ANTERIOR NECK LENGTH</u> - The subject sitting in erect posture. Surface distance from suprasternale to the juncture of the chin and neck is measured with sliding calipers.

15. <u>POSTERIOR NECK LENGTH</u> - The subject is seated in erect posture. Surface distance is measured from cervicale to the lowest point of occipital region (at or below inion) with sliding calipers.

16. <u>LATERAL NECK BREADTH (mid)</u> - The subject is seated in erect posture. Diameter is measured with anthropometer at mid-point of neck from left to right side.

17. ANTERIOR-POSTERIOR NECK BREADTH (mid) - The subject is seated in erect posture. Diameter is measured with anthropometer at mid-point of neck from front to rear.

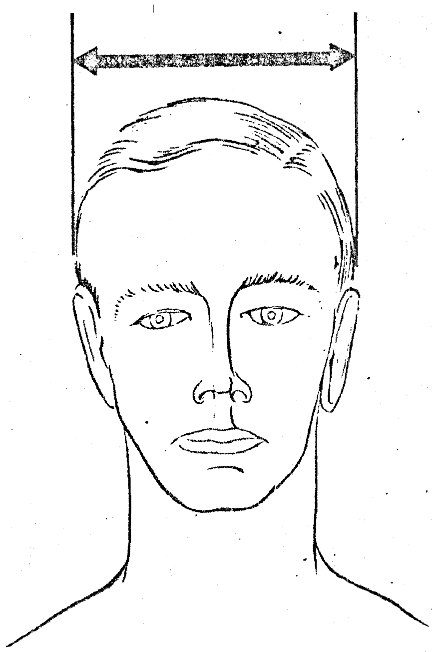
18. SUPERIOR NECK CIRCUMFERENCE - The subject is seated in erect posture. The horizontal circumference from juncture of chin and neck to lowest point of occipital region (at or below inion) is measured with tape.

19. INFERIOR NECK CIRCUMFERENCE - The subject is seated in erect posture. The horizontal circumference from juncture of chin and neck to lowest point of occipital region (at or below inion) is measured with tape.

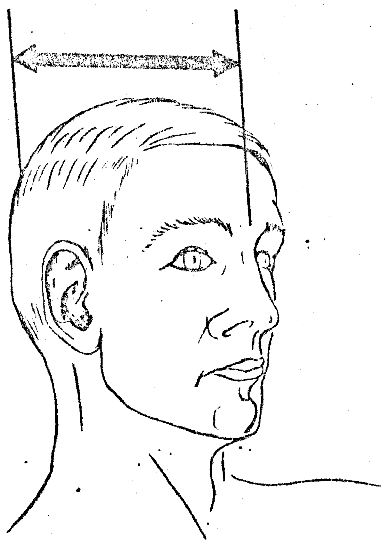
20. HEAD CIRCUMFERENCE - The subject is seated in erect posture. The maximum circumference of the head is measured with a steel tape passing over the brow ridges and held perpendicular to the mid-sagittal plane (but not necessarily horizontally).

21. HEAD ELLIPSE CIRCUMFERENCE (Bennett) - The subject is seated in erect posture. The head circumference from menton (chin) to point on back of head at maximum distance is measured with a steel tape.

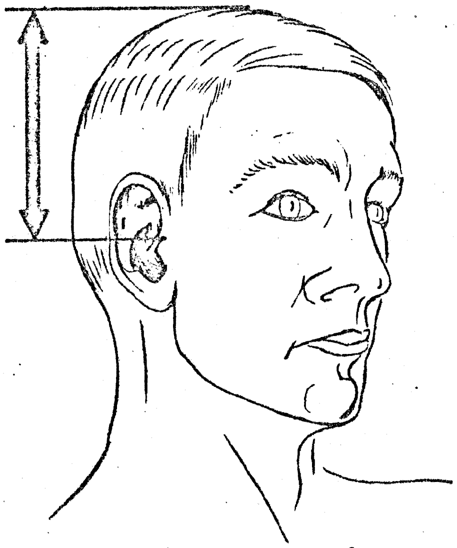
22. <u>HEAD BREADTH</u> - The subject is seated in an erect posture. The maximum breadth of the head is measured with the spreading caliper perpendicular to the mid-saggital plane of the head.



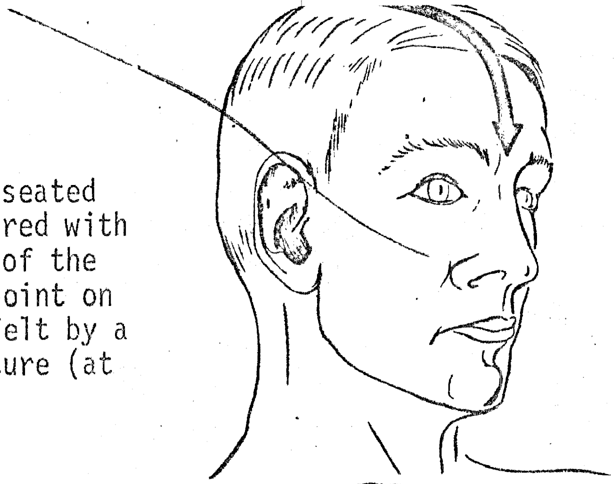
23. <u>HEAD LENGTH</u> - The subject is seated in an erect posture. The maximum length of the head is measured from glabella to the occipital region in the mid-saggital plane of the head with the spreading caliper.



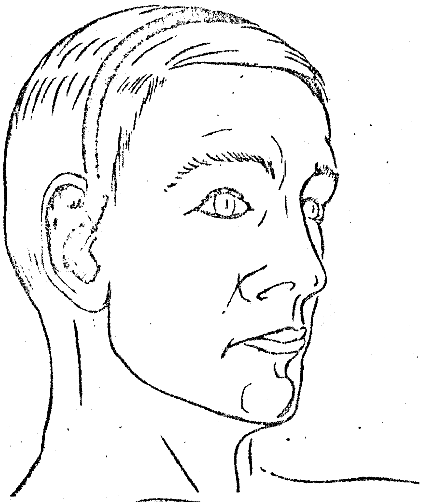
24. <u>HEAD HEIGHT</u> - The subject is seated in an erect posture. The vertical distance is measured from tragion to the highest point of the skull with the anthropometer.



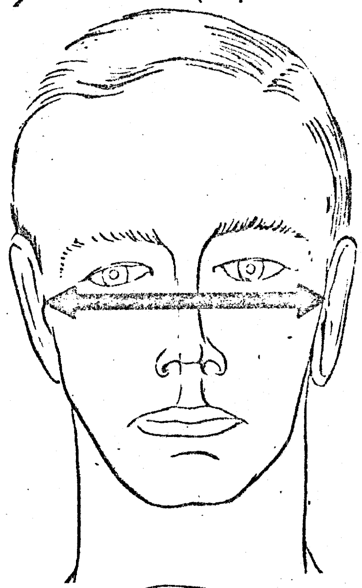
25. SAGITTAL ARC - The subject is seated in an erect posture. The arc measured with the tape in the mid-sagittal plane of the head, from glabella to the lowest point on the base of the skull that can be felt by a firm touch amid the nuchal musculature (at inion or below).



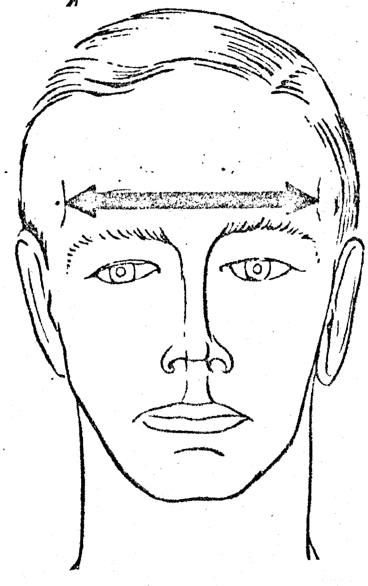
26. CORONAL ARC - The subject is seated in an erect posture looking straight ahead. The arc is measured from right to left tragion over the top of the skull with the steel tape in a vertical plane.



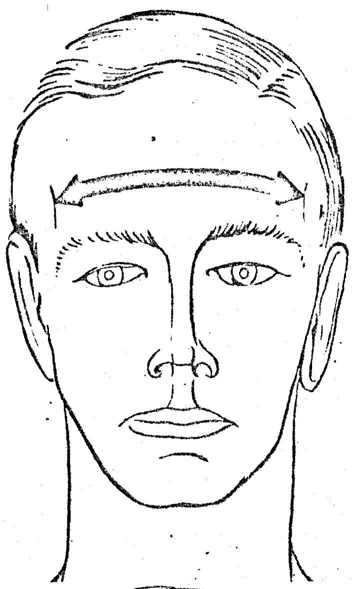
27. BITRAGION DIAMETER - The subject is seated in an erect posture. The diameter between right and left tragion is measured with light contact and holding the spreading caliper in a horizontal plane.



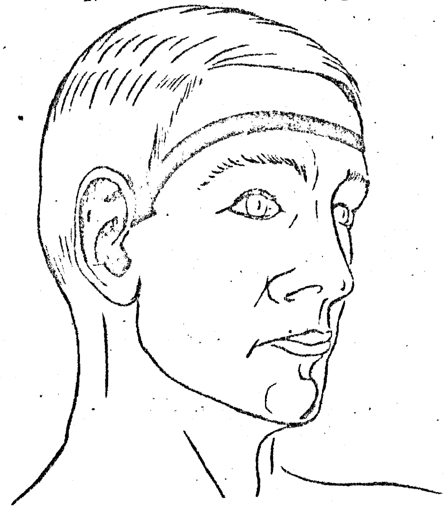
28. MINIMUM FRONTAL DIAMETER - The subject is seated in an erect posture. The minimum diameter is measured with the spreading caliper across the temporal crests at their point of greatest indentation. Care must be taken that the measurement is made on the crests and not over the temporal muscles.



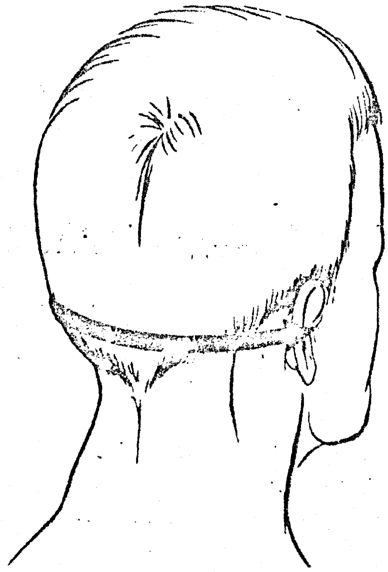
29. MINIMUM-FRONTAL ARC - The subject is seated in an erect posture. The arc is measured across the forehead, above the brow ridges, with the tape passing across the crests of the temporal muscles at their points of greatest indentation toward the mid-sagittal plane of the head.



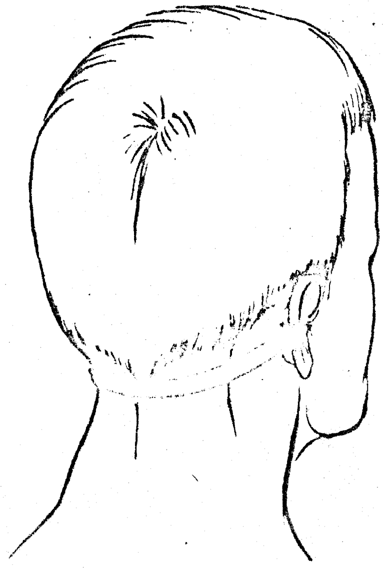
30. BITRAGION-MINIMUM FRONTAL ARC - The subject is seated in an erect posture. The arc is measured from right to left tragion with a steel tape over the region of the minimum frontal arc.



31. BITRAGION-INION ARC - The subject is seated in an erect posture. The arc from right to left tragion is measured with the steel tape passing over inion.

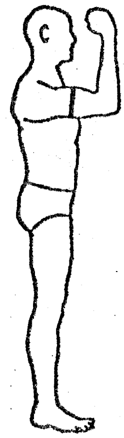


32. POSTERIOR ARC - The subject is seated in an erect posture. The arc is measured from right to left tragion with the steel tape passing over the lowest point of the skull where the nuchal musculature attaches.

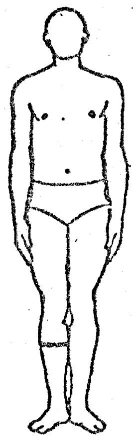


C. Skinfold Measures

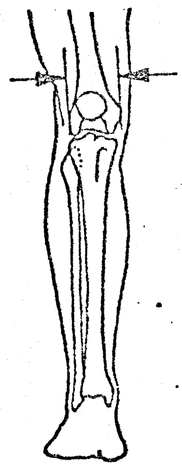
1. BICEPS FLEXED CIRCUMFERENCE (Right) - The seated subject maintains an erect posture with his arms hanging freely at the side. The subject flexes his right arm at least 90°, makes a fist while holding his upper arm horizontal to the floor, and flexes his biceps to the maximum. The measurement is made with a steel tape at the maximum circumference of the upper right arm.



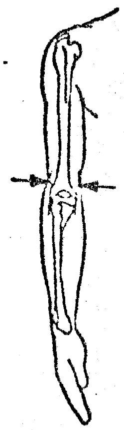
2: CALF CIRCUMFERENCE - The standing subject maintains an erect posture with his weight equally distributed and legs slightly apart. The maximum circumference of the right calf is measured with a steep tape.



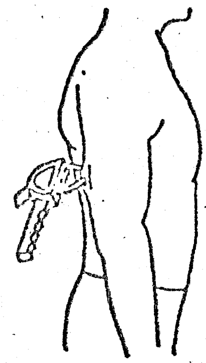
3. FEMORAL BIEPICONDYLAR DIAMETER - The subject maintains an erect posture with feet spread slightly apart. Using an anthropometer the horizontal distance is measured between the medial and lateral epicondyles of the right femur.



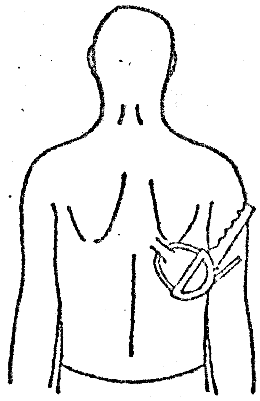
4. HUMERUS BIEPICONDYLAR DIAMETER - The distance between the lateral and medial epicondyles of the right humerus is measured with a sliding caliper with the arm hanging freely at the side.



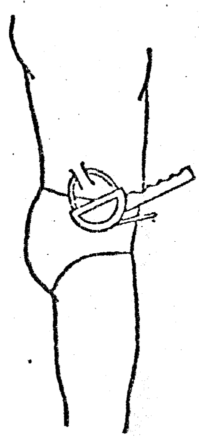
5. RIGHT TRICEPS SKINFOLD - The point of measurement is located on the dorsal aspect of the right arm of the standing subject, midway between the acromion and tip of the elbow (olecranon) when the forearm is flexed at 90°. The subjects arm is then extended to hang freely, the skinfold is lifted parallel to the long axis of the arm by firmly grasping a fold between the thumb and forefinger about 1 centimeter from the point to which the Lange caliper is applied. A reading is made within 3 seconds after application of the caliper, and the average is taken of several readings.



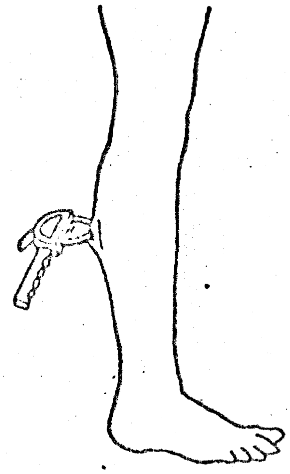
6. RIGHT SUBSCAPULAR SKINFOLD - This site is located on the standing subject below the inferior angle of the right scapula. The skinfold is lifted in a direction parallel to the ribs, with the skinfold angled upward medially and downward laterally at about 45 degrees from the horizontal. A reading is made with the Lange caliper within 3 seconds after application of the caliper, and the average is taken of several readings.



7. RIGHT SUPRAILIAC SKINFOLD - This site is located on the standing subject superior to the lateral aspect of the iliac crest on the right side. The skinfold is lifted parallel to the pelvis and angled slightly upward medially. A reading is made with the Lange caliper within 3 seconds after application of the caliper, and the average is taken of several readings.



8. RIGHT POSTERIOR MID-CALF - This site is located on the standing subject half way between the popliteal and alteral malleolus of the dorsal aspect of the lower leg, mid-way between the ankle and knee. The skin-fold is lifted parallel to the leg, and a tight skin adhesion is most commonly found here. A reading is made with the Lange caliper within 3 seconds after application of the caliper, and the average is taken of several readings.

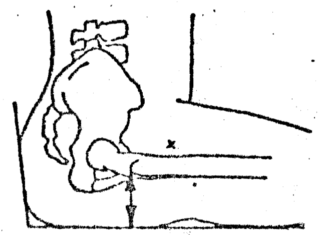


8 ADDITIONAL MEASURES TO CONSIDER (Problem - most require minimum clothing to obtain)

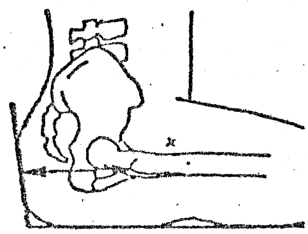
SEATED HIP BREADTH - The subject is seated in erect posture. The horizontal distance is measured with an anthropometer across the maximum breadth of the hips, applying only light contact pressure.

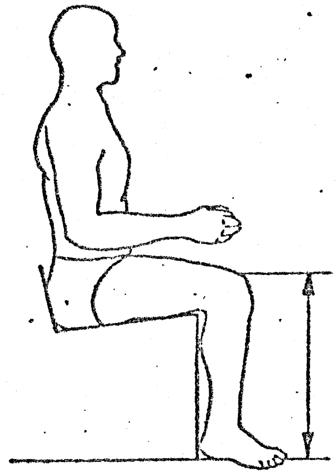
SEATED HEIGHT OF RIGHT ANTERIOR ILIAC SPINE - The subject is seated in erect posture. The vertebral distance is measured with an anthropometer from the sitting surface to the anterior superior iliac spine of the right ileum.

SEAT SURFACE-TROCHANTERION (Vertical, Seated) - The subject sits erect with buttocks against the seat back, arms resting on upper legs, and lower legs together and at a 90° angle to the upper legs. The vertical distance is measured with an anthropometer from trochanterion, located while the subject is seated, to the superior surface of the seat. The seat back angle is 13° back from the vertical and the seat pan angle is 6° up from the horizontal.

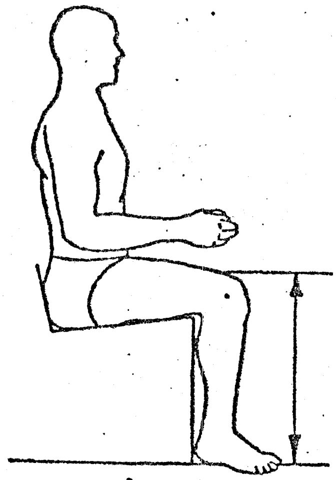


SEAT BACK-TROCHANTERION (Horizontal, Seated) - The subject sits erect with buttocks against the seat back, arms resting on upper legs, and lower legs together and at a 90° angle to upper legs. The horizontal distance is measured with an anthropometer from trochanterion, located while the subject is seated, to the anterior edge of the seat back. The seat back angle is 13° back from the vertical and the seat pan angle is 6° up from the horizontal.

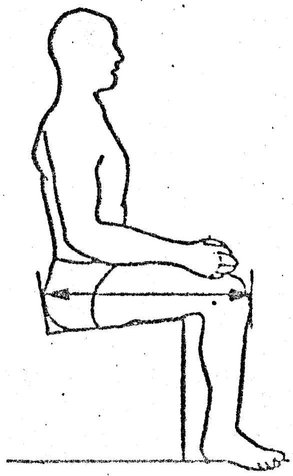




SITTING KNEE-HEIGHT - The subject sits erect with buttocks against the seat back, arms resting on upper legs, and lower legs together and at a 90° angle to upper legs. The vertical distance is measured with an anthropometer from the floor to the superior point of the patella.



SITTING KNEE HEIGHT (Maximal Clearance) - The subject sits erect with buttocks against the seat back, arms resting on upper legs, and lower legs together and at a 90° angle to upper legs. The vertical distance is measured with an anthropometer from the floor to the highest point of the right knee. This point will be superior to the preceding measurement and provides maximum knee clearance distance.



BUTTOCK-KNEE LENGTH - The subject sits erect with buttocks slightly forward from the seat back, arms resting on upper legs, and lower legs at a 90° angle to upper legs. The horizontal distance is measured with an anthropometer from the right buttock to the most anterior aspect of the right kneecap.

CHIN-NECK INTERSECT - The subject maintains an erect posture, feet together, arms hanging at his side, looking straight ahead with head held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the floor to the point of intersection of the chin and neck at the mid-line. This intersection is located by observing the subject from the side and marking the highest point on the neck intersected by the chin.

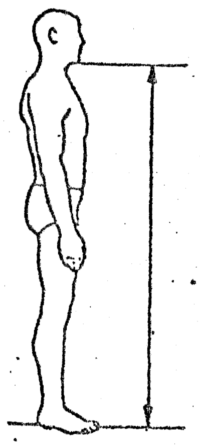


TABLE VI.

DESCRIPTION OF SURFACE MARKER LOCATIONS USED AS REFERENCE POINTS FOR PHOTOMETRIC AND RADIOGRAPHIC ANALYSIS

A. Radiographic Markers (lead shot):

1. Cervicale - The point on the surface of the skin at which the most superior dorsal aspect spinous process of the seventh cervical vertebra can be palpated.

2. C_5 - The point on the surface of the skin at which the most superior dorsal aspect spinous process of the fifth cervical vertebra can be palpated.

3. Right Tragion - On the right ear, the cartilaginous notch anterior to the superior lip of the auditory meatus (posion).

4. Nasal Root Depression - The point of greatest indentation where the bridge of the nose joins the supraorbital ridge of the forehead.

5. Suprasternale - The superior margin of the jugular notch of the manubrium.

B. Photometric Markers:

1-5. Coinciding with locations described above

6. Right Acromion - The superior and external border of the acromion process of the right scapula.

7. Head of the Humerus - Measured from the right acromion over the lateral surface of the arm on a line projected inferiorally from the acromion to the lateral epicondylea distance of 2 inches.

5. Radiography

Since the radiography is being used as a major tool for clinical selection of subjects it was important to get the Radiology Laboratory modified, the techniques established, and take initial x-rays on preliminary subjects as soon as possible. These goals have been accomplished and we have completed initial analysis of the first subjects.

The x-rays are intended to serve two purposes. Besides use to clinically evaluate any factors that might increase risk of injury to the subject, they will be used in photogrammetric analysis to obtain cervical measurements such as vertebral interspaces, bone-to-skin surface dimensions, and neck angles. Comparison of x-ray and 35 mm photogrammetry results will be made.

With the assistance of the Picker x-ray service supervisor for this area the x-ray laboratory equipment has been repositioned, with the table and bucky set up on end. This allows for 40" and 60" tube-to-film distance as required for our needs. Sufficient cassettes, film, and developing materials have been obtained. In addition, two subject seats have been constructed. A rigid seat duplicates the seat being used in the Cervical Measurements Laboratory, while a 1972 Pinto bucket seat has been modified to duplicate the seat pan and back angle (103°) of the rigid chair. These seats are equipped with rollers to allow rapid change in position. Thus the x-ray laboratory has been modified, additional equipment constructed, and supplies obtained, and is fully equipped for subjects.

The protocol which has been established consists of the following views:

1. Anterior-posterior, subject seated in rigid chair (Figure 4).

2. Right lateral, subject seated in soft chair in neutral position to simulate automobile passenger position.

3. Right lateral, subject seated in rigid chair in neutral position (Fig. 5). This duplicates the automotive (soft) seat exposure and allows some comparison of laboratory and vehicle seating conditions. This is also duplicated by the

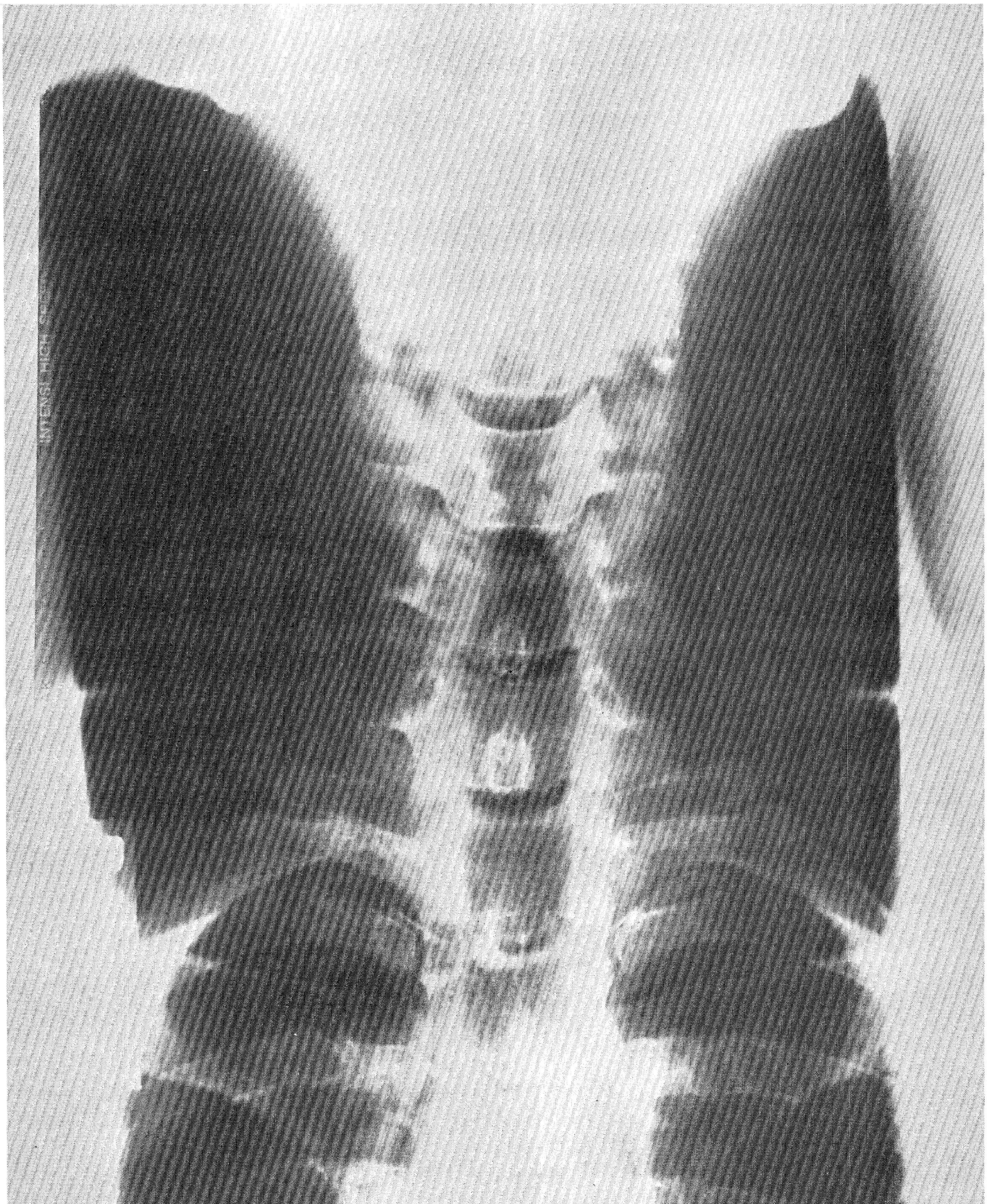


Figure 4. Cervical Radiograph, Anterior-Posterior View.

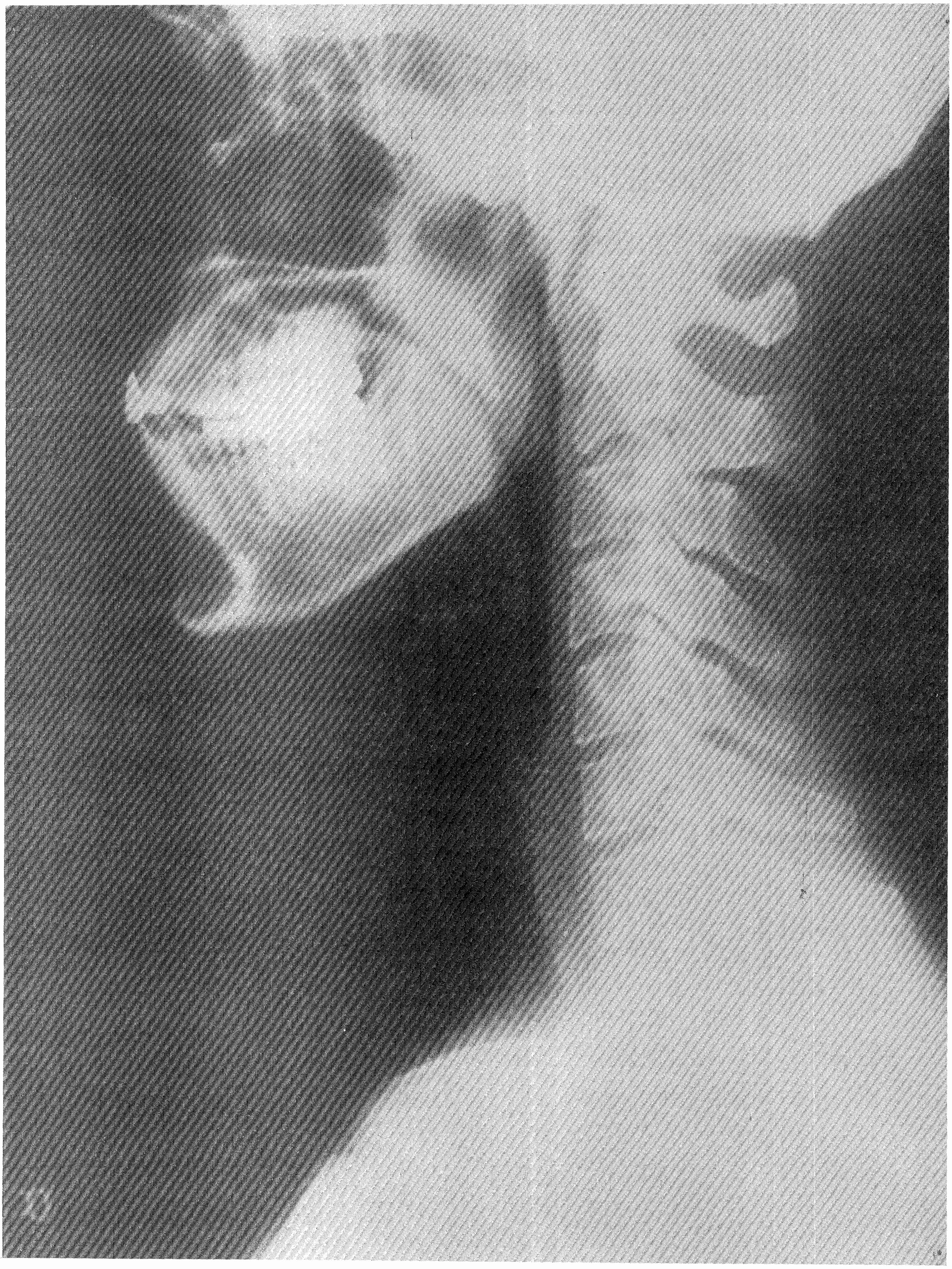


Figure 5. Cervical Radiograph, Right Lateral View, Normal Sitting Position.

position photographed in the measurements laboratory to allow comparison with surface anthropometric marker analysis.

4. Right lateral, subject seated in rigid chair, with maximum voluntary cervical hyperflexion (Figure 6). This will be duplicated by measurement laboratory photograph.

5. Right lateral, subject seated in rigid chair, with maximum voluntary cervical hyperextension (Figure 7). This position will also be duplicated by a measurement laboratory photograph.

Initially, an anterior-posterior odontoid x-ray was also taken, in which the subject lowers head and opens his mouth wide. The purpose of this view was to allow better definition of the 1st and 2nd cervical vertebrae, where arthritic conditions might be most prevalent. This view was for medical screening purposes only and has been eliminated for subsequent subjects.

Figures 8 and 9 show the present arrangement of the Radiology Laboratory. In the upper photograph (Figure 8) the subject is seated in the rigid seat, and in the lower photograph (Figure 9) note the soft automotive seat.

A numbering code for x-ray identification has been developed as follows:

Male = M
Female = F
Age 18-24 = A
Age 35-44 = B
Age 65-74 = C
0-20%ile stature = X
40-60%ile stature = Y
80-99%ile stature = Z
Subject = 01 to 12

For example, subject number one of 18-24 year old age group, of 1-20%ile stature would be coded as MAX01 Right, if male, or FAX01 Right, if female. MCZ01, would indicate a male in the 65-74 year old age group, 80-90%ile stature, and specifically identify him as the first subject. This code will match the subjects' file and allow specific identification while keeping the subject's name confidential.

Figure 6. Cervical Radiograph, Right Lateral View, Hyperflexion.

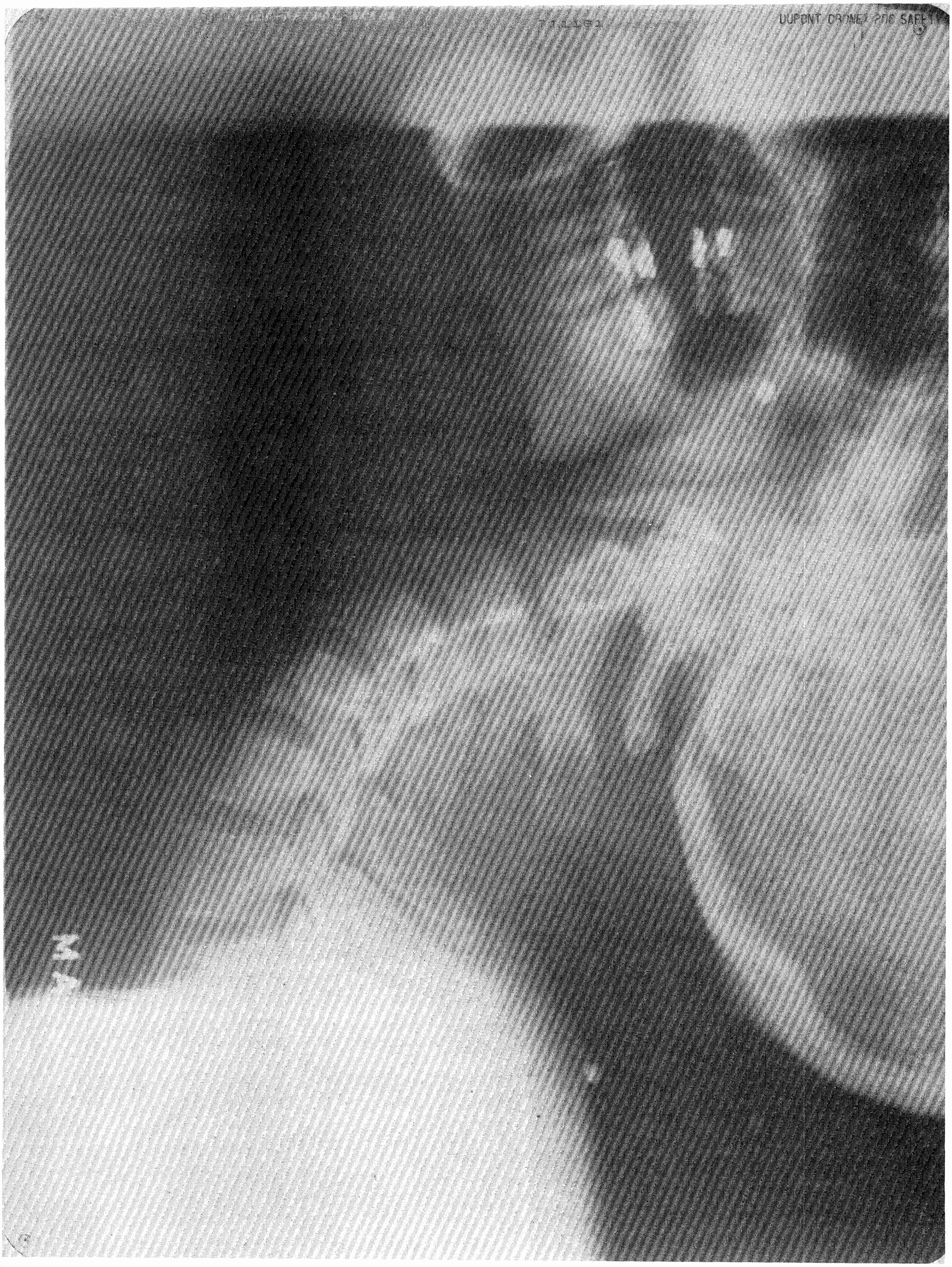


Figure 7. Cervical Radiograph, Right Lateral View, Hyperextension.

Figure 8. Radiography Laboratory View of Subject in Rigid Seat in Preparation for X-ray.

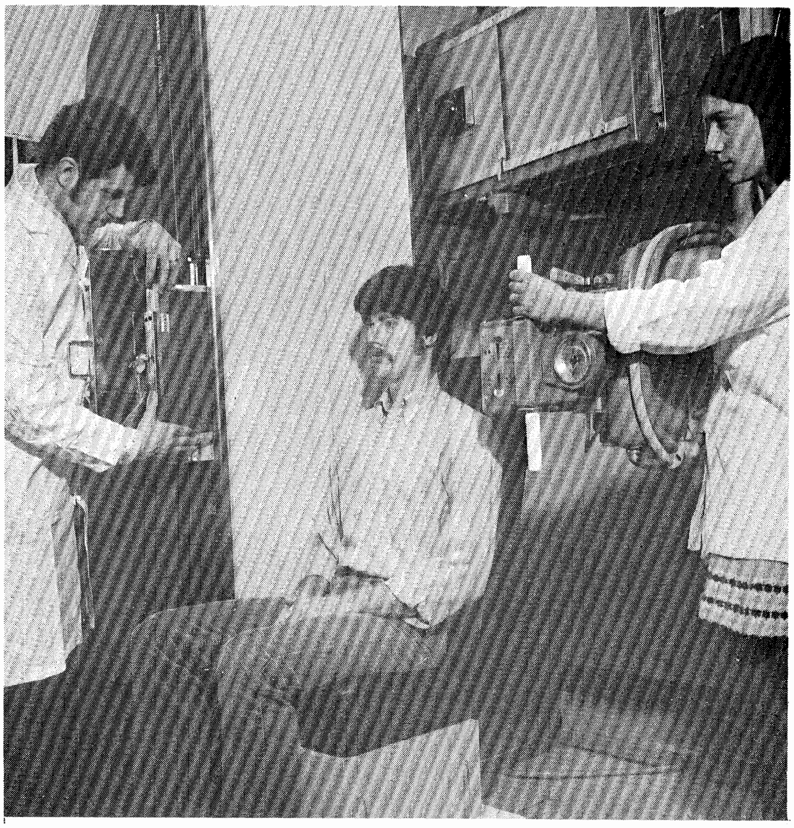


Figure 9. A View of the Subject in the Soft Seat Device in the Radiography Laboratory.

In two of the first three subjects, lead shot markers were placed on various surface landmarks. Sites tried were cervicale, C-2, right tragion, inion, suprasternale, nasion, and the temporal-mandibular joint. While the dorsal neck markers are useful to indicate the great amount of skin excursion, it was felt that more accurate bone measures can be obtained directly from measurements on the x-ray.

We have also had difficulty visualizing the head-neck relationship for some individuals particularly in hyperflexion views where the head is almost completely off the x-ray plate. In this respect we intend to try larger size film to obtain more in the picture. However, this will have to be balanced against additional radiation measures (and possibly fewer views), and a potential problem of less contrast. We initially used 8 x 10 radiographic film size, which has proved to be too small for adequate coverage except for the A-P view. We are presently trying 10" X 12" film size, and on the last subject this has made a large improvement. However, landmarks such as nasion and tragion are still off the film, and we are considering 11" X 14" film size for subsequent subjects. Several techniques of insuring accurate measurement have been tried and at present a scale of known dimensions is being exposed in the x-ray view.

Figures 4-7 are included to indicate typical views for each subject. Note that lead shot markers have been used in several instances, but that not all markers are consistently shown in the various views. An interesting observation is that, even in the limited number of subjects which have been x-rayed to date, we have found considerable variation in ability to exert maximum voluntary flexion or extension, and that the resultant shape of the cervical spine curvatures varies between individuals for the same motion. Reproducible standardization of these subjects for these views must still be examined further when x-ray films from additional subjects are available.

6. Electromyography, Strength Measurements and Photometrics

During this initial phase of the study the emphasis has been upon designing, ordering, or constructing necessary equipment and getting the cervical measurements laboratory set up for subsequent testing (Figure 10). Accomplishments to date primarily reflect these objectives.

The current status of the equipment to be utilized in the portions of the study related to the EMG stretch response measurements, the neck muscle strength, and photogrammetry techniques are as follows:

(1) Framework of Text Fixture. This has been designed, constructed, and installed in the cervical measurements laboratory.

(2) Rigid Seat. Designed, built, and installed in the cervical measurements laboratory. This seat features on adjustable back to allow for stature differences. (Note that a total of four seats are being used, and all have now been constructed. The others consist of both hard and soft seats for the Radiology Laboratory, the soft seat being constructed around a 1972 Pinto automotive seat, and a hard seat with flat surface to be used in taking seated anthropometric measurements.)

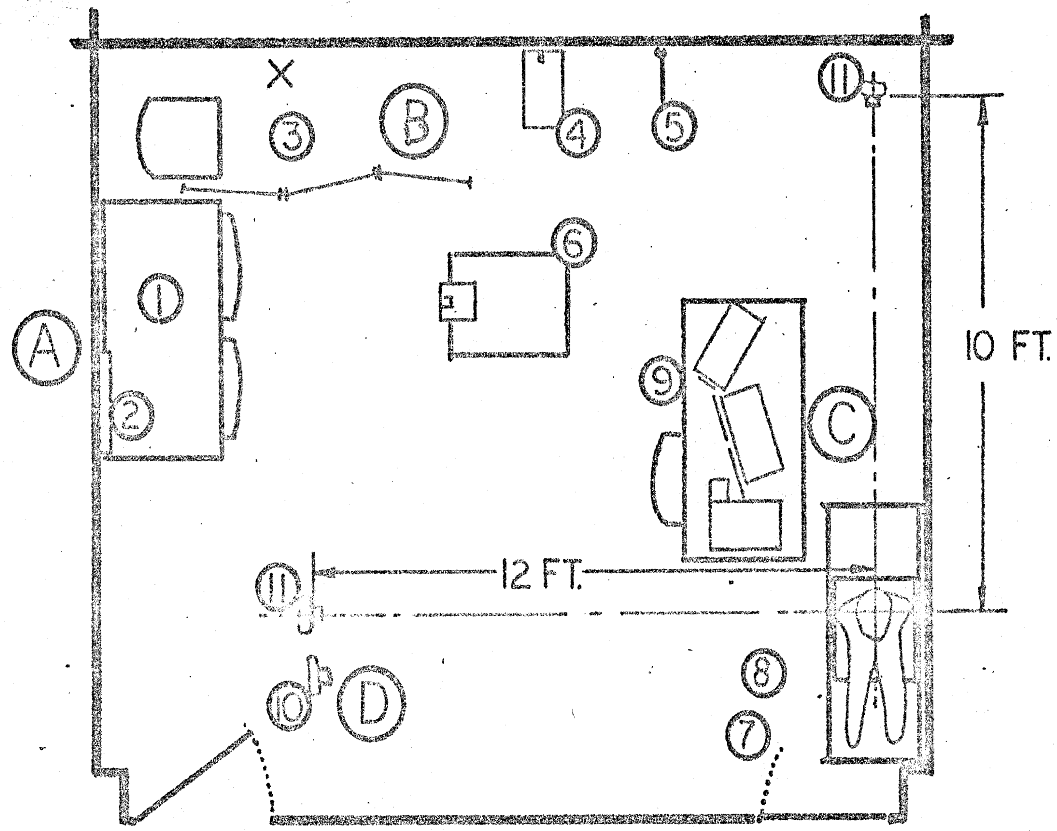
(3) Mounting Frame for measurement transducers. This has been designed and is in process of construction.

(4) Neck Strength Transducer. The design is completed and force rings and strain-gages are built.

(5) Impulse Triggering Mechanism. Currently under design, and materials for fabrication have been obtained or are readily available.

(6) Headpiece for impulse loading. A temporary device is available for preliminary tests, however an improved permanent device is under design based upon additional requirements.

Figure 10. Physical Organization of the Cervical Measurements Laboratory.



A. Briefing Area

1. Table - reading and subject briefings
2. X-ray viewer

B. Anthropometry Area

3. Dressing area - chair, clothes rack, screen
4. Scales
5. Anthropometer
6. Rigid chair for anthropometric measurements

C. Active Measurements Area (Range of motion, neck strength, muscle reaction time)

7. Test fixture - devices mount to supports
8. Rigid chair and subject
9. Equipment table - tape recorder, amplifiers, oscilloscope

D. Photography Area

10. Graph-check camera and lights - stop-action
11. 35 mm cameras and lights - photogrammetry

(7) Electronic Equipment

The major piece of equipment necessary for this study has been determined to be a 7 channel (plus voice track) Ampex PR-500 FM Tape Recorder. Since an additional number of channels was found to be required for this study over the estimated needs, a cost sharing agreement between the Highway Safety Research Institute and the College of Engineering, in which the College of Engineering will contribute some $4100 additional funds above that budgeted, will enable us to upgrade this equipment. At the moment the order is being held up pending agreement between the University of Michigan and the sponsors relative to disposition at the termination of this study. Although we have been assured 30 to 45 day delivery by Ampex this item remains the major obstacle to initiating tests. In the interval we are hopeful of obtaining similar equipment on loan, but if we are not successful, this may delay our schedule.

Accelerometers, to be mounted on the headpiece to measure angular and linear acceleration, have been received from the manufacturer.

Accelerometers have been ordered in February and we anticipate delivery by the end of March. These will be mounted on the headpiece to measure angular and linear acceleration.

Amplifiers for acceleration, EMG, force, and displacement channels are being designed and built in the Human Performance Laboratory. For initial tests others are available, and we may modify our amplifiers at that point to allow better definition of parameters.

(8) Photographic Equipment

For the 35 mm photogrammetry the two necessary cameras and camera stands have been obtained and are mounted in position in the cervical measurement laboratory. Electronic shutter releases are being prepared. Lighting will be available when needed.

A Graph-Check high-speed Polaroid camera has been ordered. Through a series of special lenses eight exposures in sequence are made on a single 4 X 5 inch black and white Polaroid film. Similar equipment has been used in kinematic motion studies and has proven a very useful tool in impact sled tests, vehicle barrier crash tests, and human, dummy, and animal experimental sled decelerations. We plan to use this camera for high-speed photographic recording of extension and flexion impulse tests of each subject to document the degree of flexion/extension experienced. In addition it is felt that this documentation might be of critical clinical value should a subsequent medical-legal problem arise in which a subject might attribute trauma to the tests.

7. Cervical Measurements Laboratory Test Protocol

Modifications to the detailed procedures are still being made and it is anticipated that further refinements will be accomplished as a result of the initial subject tests. As noted earlier, the subject is tested in two phases, and is not accepted for these tests until he has been medically cleared by the Radiologists on the basis of his health history questionnaire (and follow-up if necessary), and x-ray films. The general procedure that will be used is as follows:

(1) The subject will receive a thorough briefing on the test procedures involved, including having the subject repeat his understanding of the procedures in conformance with University Medical School requirements of the Committee for Clinical Research and Investigation Involving Human Beings.

(2) Anthropometry will be taken. (We are presently considering incorporating this step earlier, to be accomplished at the time x-rays are taken). A special seat has been designed and constructed for the seated measurements.

(3) Landmarks will be placed on the body at several locations to be used in photogrammetric analysis.

(4) The subject will be seated in a rigid seat, which has been designed with an adjustable seat back height to stabilize the upper torso . The remainder of the test procedures (4)-(8) will be accomplished with the subject in this rigid seat.

(5) 35 mm photographs will be taken of the subject from two angles, right lateral and from the dorsal aspect. The subject will be photographed in neutral position, maximum voluntary hyperflexion and hyperextension positions. These photographs are intended to duplicate the x-rays already taken and will be used in photogrammetric analysis.

(6) The subject will be asked to exert a maximum voluntary isometric exertion using first flexor, then extensor muscle groups. Maximum voluntary

forces will be determined as a measure of the strength of the muscle groups. Each test will consist of three trials, each trial of 4 seconds duration, with 30 seconds of rest between trials.

(7) The head piece will be fitted and EMG electrodes will be placed on the skin surface over the sternomastoid and semispinalis muscles. After the subject is acclimated and comfortable, training effects will be eliminated by releasing the weight once or twice, which should convince subjects that the test is not harmful. The subject will then be asked to relax the muscles of the neck (EMG activity will be monitored on an oscilloscope so the weight will be released when the muscles are indeed relaxed.) Several trials will be recorded in both flexion and extension loading and data on accelerations, reaction times, and head displacement will be obtained. The Graph-Check camera will also be utilized to provide a stop-motion sequential documentation of this test.

(8) At the completion of these measurements, the headpiece and electrodes will be removed, the subject will be asked about his reaction to the tests and how he feels (taking care not to ask any leading questions), and the subject will be thanked for his participation, paid, and excused.

8. Mathematical Modeling Studies

A series of computer exercises is being conducted using the HSRI Two-Dimensional Crash Victim Simulator (Robbins, 1971) to determine how individual differences in human anatomy and physiology can influence production or avoidance of cervical injury. This first group of computer exercises uses what limited data are available in order to isolate those biomechanical variables which are most sensitive in reducing or increasing head-neck relative motion and associated G-levels.

Mathematical Model Test Matrix

Approximately fifty completely successful computer exercises have been conducted up to the present time and the results have been analyzed. The test matrix for this series is shown in Table VII. Three of the four groups of exercises included in the proposal have been completed including neck muscle strength, voluntary range of motion, and anthropometry. Variation of muscle response time is being conducted at the present time.

Determination of Input Data

Three types of input data are required for the exercising of mathematical models: crash description, vehicle interior description, and occupant description. The crash which is used as a baseline corresponds to a rear-end collision with a final velocity differential of 30 mph. This approximates one car impacting another with a closing rate of 50-60 mph. The chosen pulse is derived from work conducted at HSRI (Melvin, 1971) and is shown in Figure 11.

The vehicle interior is described in terms of a seat back, seat cushion, floorboard, toeboard, and lap belt. No head rest is provided. The seat back and seat cushion angles are chosen to match the Ford Pinto seat being used in the human measurement part of this project. The force-deformation properties

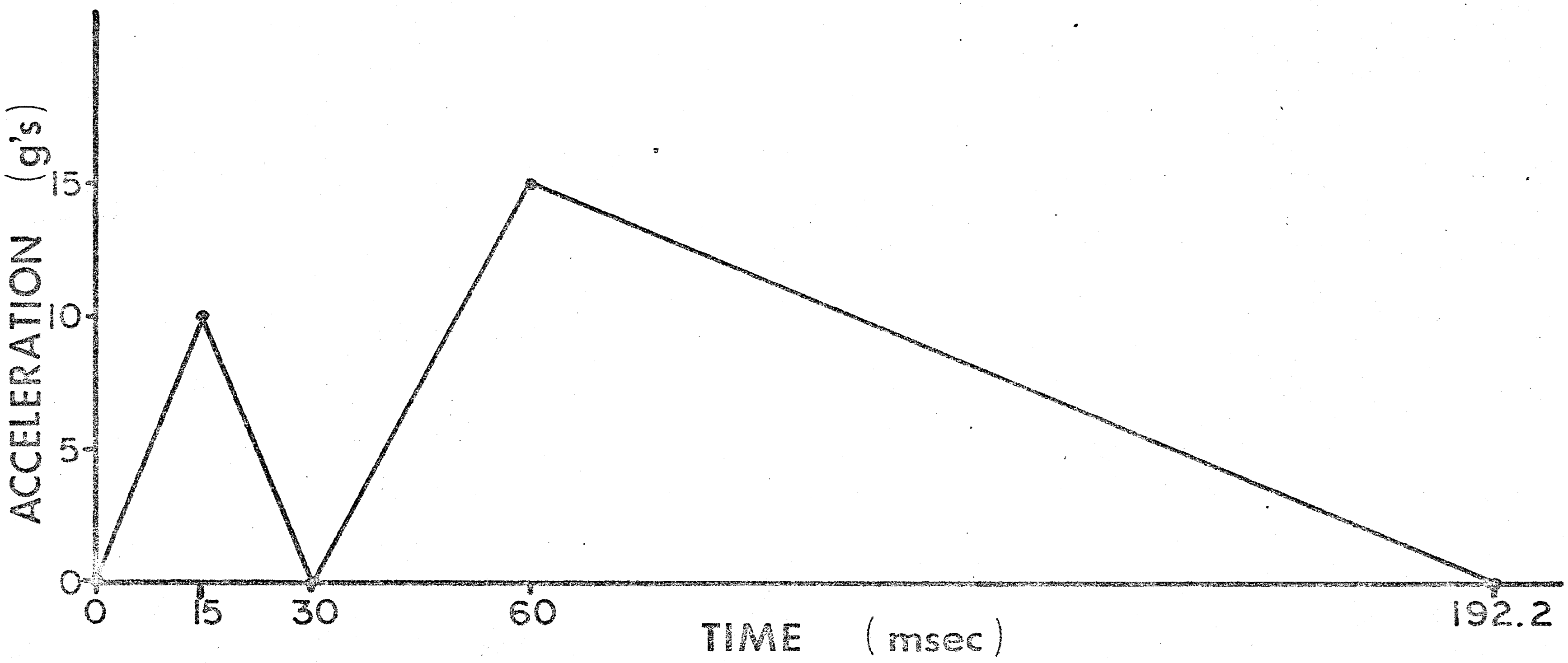


Figure 11. Rear-end Collision Crash Pulse.

TABLE VII.

MATHEMATICAL MODEL EXERCISE MATRIX

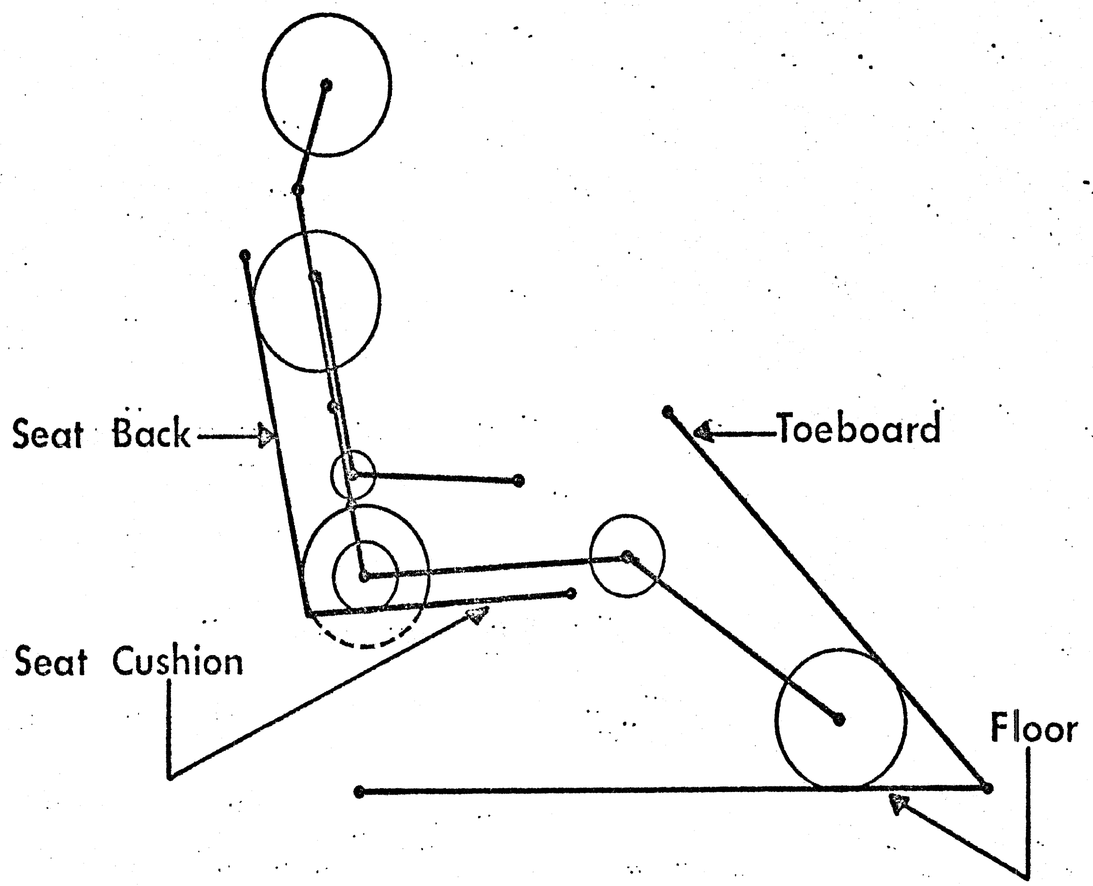
Physical Variable	Value
Neck Muscle strength	1. Muscles relaxed. 2. Muscles tensed to estimated maximum voluntary level. 3. Muscles tensed to 0.1 maximum. 4. Muscles tensed to 0.5 maximum. 5. Muscles tensed to 5.0 maximum.
Voluntary Range of motion	1. Voluntary range of motion in neck extension set at 70°. 2. Range of motion increased to 95°. 3. Range of motion decreased to 45°.
Strength of neck motion limiting structures (ligaments, bone, cartilage, etc.)	1. Value of stop set at 10 times the value estimated for maximum muscle strength. 2. Value set at 2 times value of maximum muscle strength. 3. Value set at 50 times value of maximum muscle strength.
Anthropometry (Location of Centers of gravity, e.g.)	1. Upper torso length shortened from 12.59 in. to 8.39 in. 2. Upper torso length increased from 12.59 in to 16.79. 3. Distance to head c.g. increased from 4.86 in. to 6.48. 4. Distance to head c.g. decreased from 4.86 in to 3.24 in.
Anthropometry (Head weight)	1. Head weight chosen to match 50% Sierra dummy. 2. Head weight decreased by 50%. 3. Head weight increased by 50%.
Anthropometry (Head Moments of Inertia)	1. Moment of inertia chosen to match 50% Sierra dummy. 2. Moment of inertia decreased by 50%. 3. Moment of inertia increased by 50%.
Anthropometry (Percentile of occupant)	1. 50th percentile male. 2. 95th percentile male 3. 5th percentile female.

of this seat match those of a seat of similar construction which was measured during HSRI model verification tests (Robbins,1971). A lap belt installation is provided to supplement seat back friction in minimizing "ramping" up the seat back. This tends to magnify whiplash while minimizing whole-body motion and the potential for other vehicle interior contacts.

The basis for the occupant description is a 50th percentile Sierra dummy which has been subject to extensive measurements at HSRI. These data have been modified where appropriate human data are available. In particular, the friction joints used in the dummy were replaced by elastic stops based on recent work at HSRI (Bowman,1971). Bowman has estimated the elastic forces required to move the head relative to the torso based on maximum voluntary neck muscle strength. It was not possible to locate information on the strength of neck motion limiting structures including ligaments, bone, cartilage, etc. The standard value chosen for this quantity was ten times the value of neck muscle strength. Body geometry, masses, moments of inertia, etc., are based on the dummy measurements. A schematic of the occupant seated in the standard configuration is included as Figure 12. Variations on this standard configuration and data set are given in Table VII.

Results

A large amount of data are printed out after an exercise of the HSRI Two-Dimensional Crash Victim Simulator including belt forces, belt angles, hip linear position, head linear position, the angular position, velocity, and acceleration of the eight body masses, the vehicle deceleration, velocity, and position, resultant head and chest linear acceleration, seat cushion forces, and the values of the forces generated at all other vehicle-occupant contacts. Graphical output showing the position of the occupant as a function of time is also available. The variables chosen as most representative in studying the



SCHEMATIC of INITIAL OCCUPANT POSITION
for COMPUTER SIMULATION

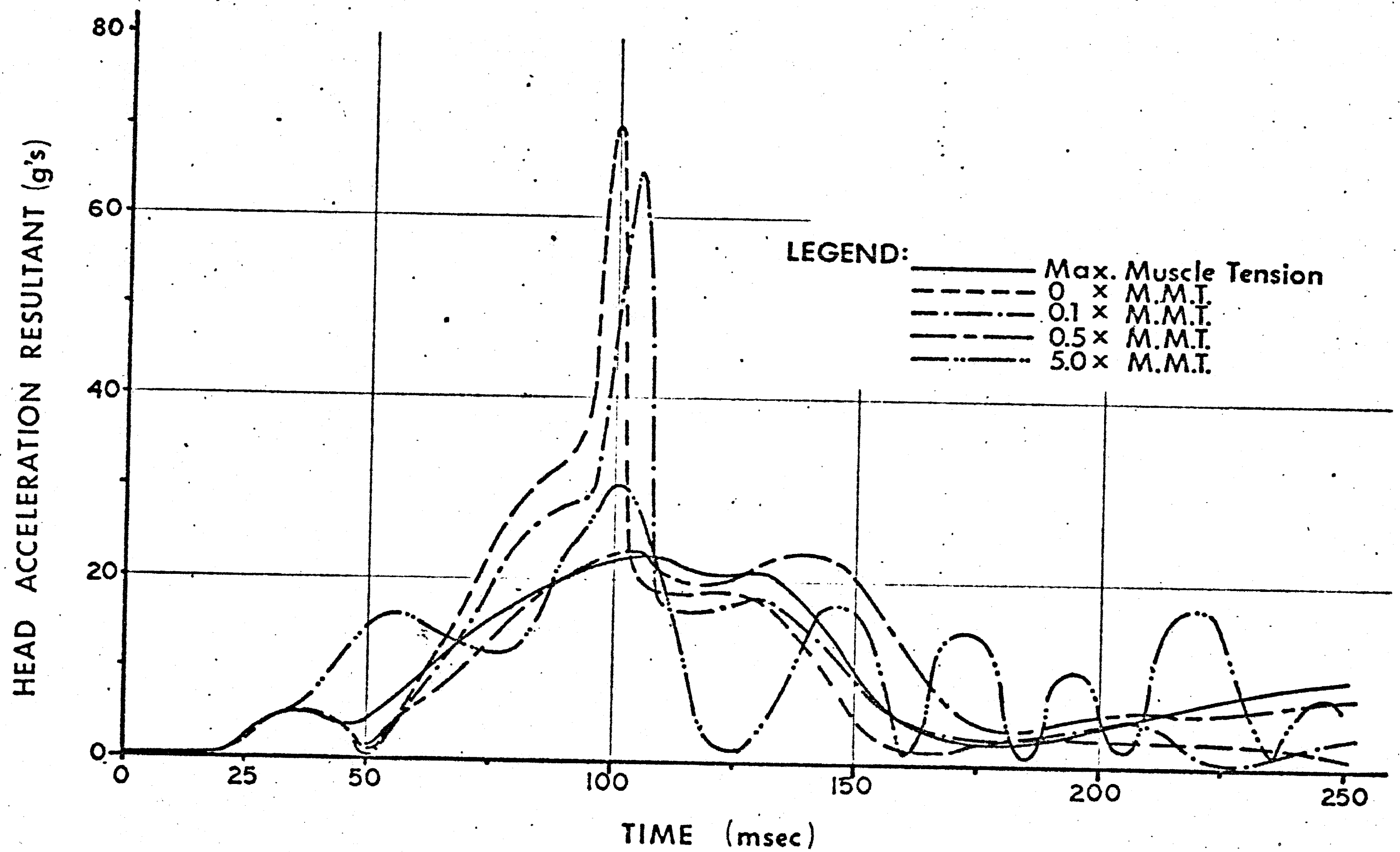
Figure 12.

head-torso interface are angular head position, angular head velocity, angular head acceleration, and head resultant linear acceleration.

When muscle strength is varied from a completely relaxed state to a value five times the estimated maximum human capacity, several observations can be made which may be related to the incidence or avoidance of injury. Angular head position and head resultant linear acceleration are given in Figures 13 and 14. Figure 13 illustrates that high accelerations result in two of the model exercises -- muscles relaxed and muscles tensed to one-tenth the estimated capacity. This results when the head rotates backward relative to the torso (without much muscle force resisting the motion) and being stopped by neck structures representing bone, ligaments, etc. This interaction was not observed to occur when the neck muscles were tensed to half their estimated strength or greater values.

These results identify two factors of interest. First, muscle strength appears to be a factor contributing greatly to head-neck kinematics and dynamics. Second, data are required to define the strength of tissues near the end of allowable non-injury range of motion.

Figure 14 shows the head angular position for the five muscle tension variation exercises. In the case where the muscles were assumed to be totally relaxed, the head moved back, contacted the motion limits and stayed there until the end of the simulation. Similar behavior is observed in dummies with loose friction joint settings. On the other end of the spectrum the head hardly moved with respect to the torso in that case where muscle strength was set at five times the estimated voluntary maximum. The head appears to oscillate back and forth as if on the end of a stiff spring. This type of behavior is sometimes observed in dummies equipped with the new rubber necks. Study of angular velocities and accelerations leads to similar conclusions.



HEAD RESULTANT G-LEVEL as a FUNCTION of MUSCLE TENSION

Figure 13.

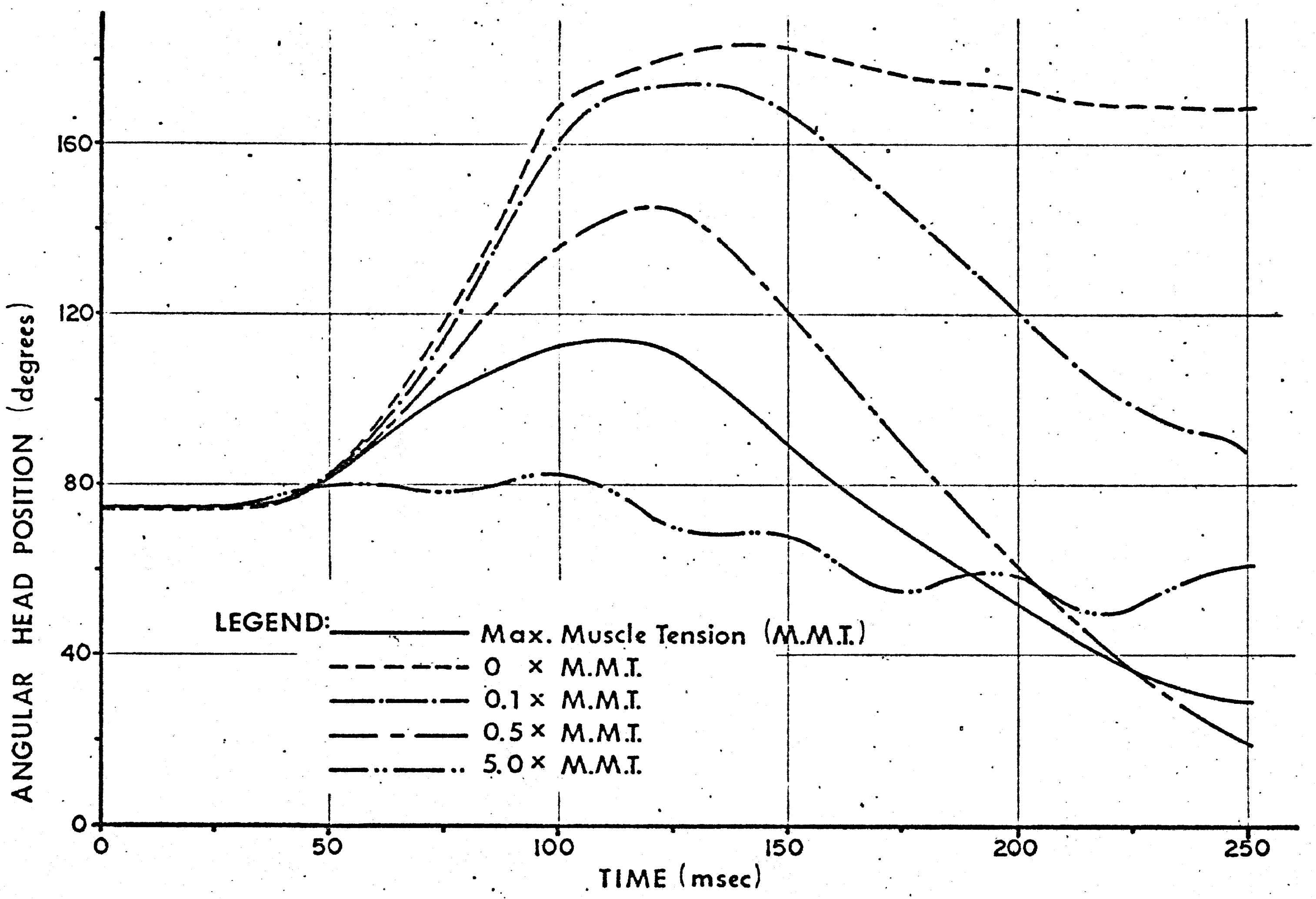


Figure 14.
HEAD ANGULATION as a FUNCTION of MUSCLE TENSION

Angular head position and head resultant G-accelerations were studied when the value of the neck stop structures was varied. The muscle strength was assumed to be zero to maximize the effect of these structures. In the baseline case the value of peak acceleration was 70 G's (see Figure 13). When the strength of this stop was increased, the peak increased to 150 G's (greater than 80 G's for approximately 6 msec). The peak decreased to 38 G's when the stop value was decreased. Although the position of the head was observed to be similar in the three cases, the loadings were not. This supports the need for data (outside the scope of this contract) describing tissue strength at motion limits. Estimates may be possible using cadavers.

The angular range of motion of the neck was also varied from 45° to 95°. Differences were noted in angular position, peak G's, time of occurrence of force interaction with the range of motion limit stop, and duration of G-level above 30 G's. The case of zero muscle strength was again chosen to maximize these effects. A summary of results is included in Table VIII. Probably the major effect of varying the neck range of motion was increasing the angulation between head and torso. This affects the location of the head within the vehicle at a given point in time and could thus influence contacts with vehicle components and possibly with other vehicle occupants.

TABLE VIII.
VARIATION OF NECK RANGE OF MOTION

Neck range of motion (degrees)	Extension of head with respect to initial position (degrees)	Peak resultant head G-level	Time of occurrence of peak G-level (msec)	Duration of head G-level above 30 G's (msec)
45	87	75	90	12
70	108	70	100	20
95	118	56	110	28

Careful comparisons were also made between simulations where the location of the head center of gravity was varied and where head weight was changed. These variables did not markedly affect either the magnitude or shape of the head resultant G-acceleration curves. As would be expected the heavier head showed greater angulation with respect to the initial position (59°) than the lighter head (25°). The result of this is a prediction that greater muscle strength is required to resist the motions of a heavy head in a collision without increasing the risk of injury. The same conclusion can be reached as distance to the head center-of-gravity is increased. This variation can be related to increasing neck lengths. The increased moment caused by perching the head mass at the top of a long neck must necessarily require greater muscle support to justify the precarious position.

Changing head moment of inertia did not have nearly as significant of an effect as the changes in head mass. When moment of inertia was decreased the angulation of the head to the rear occurred somewhat earlier in time. Angulation was slightly delayed as moment of inertia increased .

The simulations for the 95th percentile male and 5th percentile female were remarkably similar. The male experienced larger motions and absorbed greater forces (not G-levels) due to the greater mass. The simulations were carried out with variations only in body dimensions and weight. Variations in muscle strength could be expected to occur but they were not included to keep the variables changed at a minimum in the simulations. On this basis, it can be concluded that differences in the kinematics and dynamics of a small woman and a large man are more likely to be related to strength properties of the joints and muscles as well as the way the forces are distributed over the body than to body size alone.

Although simulations where muscle response time is included have not yet been completed, the importance of this variable can already be stressed. The importance of neck muscle strength has already been established. Therefore, tensing or relaxing muscles during the crash event would appear to be able to offer a substantial perturbation on head kinematics and dynamics.

Summary of Conclusions

A summary of the conclusions reached in this computer exercise includes the following items:

1. Neck muscle strength has been isolated as an important variable affecting head-neck kinematics and dynamics. Because of this, muscle response time should be considered important in the measurement program.

2. The strength of neck motion limiting structures has also been isolated as an important variable. Although outside the scope of the current project, it is possible that these quantities could be estimated using cadaver material.

3. The range of motion of the neck in extension has been found to influence the maximum angulation occurring during impact and, as such, is an important quantity to be determined, particularly from the x-ray studies.

4. The weight of the head and the location of its center of gravity have both been found to influence the angulation of the head with respect to the torso. The effect of this is to increase the forces which must be exerted by the neck musculature to restrict head motion during impact.

5. The moment of inertia of the head exerts an influence considerably smaller than that exerted by mass or center of gravity.

6. Differences in the kinematics and dynamics of a small woman compared with a large man are more likely to be related to strength properties of the musculature and joints as well as the way the forces are distributed over the body than to body size alone.

9. Data Analysis

The anticipated availability of the Ampex 7-channel tape recorder will greatly enhance the data-taking and analysis phases of the study. Data channels will be allocated as follows:

(1) linear acceleration

(2) angular acceleration

(3) EMG from sternomastoid muscle

(4) EMG from semispinalis muscle

(5) head displacement

(6) force

(7) timing and control signals-code signals for computer analysis.

. Voice track for test announcements and observations.

Data analysis will be computerized as much as possible, since a large number of samples will be analyzed. In addition to the mathematical model, three different computer programs will be used.

Photogrammetry analysis will involve transferring information from the 35 mm film to punched paper tape by means of a Data Coder. Landmarks attached to the rigid framework and to the subject will be coded onto the paper tapes and analyzed by a computer algorithm. The algorithm is available for the Hewlett-Packard 2115-A computer. The same method can be used to analyze dimensional data from the x-rays.

Analog Signal Analysis involves two algorithms which will be written for the Hewlett-Packard 2115-A computer. One will automatically sample signals from the FM tape, digitize it (using the HP A to D converter which is inter faced with the computer) and record it on computer magnetic tape. The second

Algorithm will sample from the computer tape, using the coded control signals and automatically analyze the test data. Output will be printed on a line printer and will include accelerations, displacement, forces, EMG power, and reaction times. The production of these algorithms will be largely a matter of adapting existing subroutines and algorithms to the requirements of this study.

Statistical Analyses of anthropometry and test results can be accomplished using existing programs, since a large bank of statistical algorithms exits for The University of Michigan IBM 360-67 Computer System. These will be described in subsequent reports as data are collected and analyzed.

III. WORK TO BE ACCOMPLISHED DURING THE NEXT REPORTING PERIOD, 1 APRIL - 30 JUNE.

It is anticipated that work in the second quarter will primarily initial measurements of subjects, and evaluation and final establishment of technique refinements to be followed during the remainder of the study.

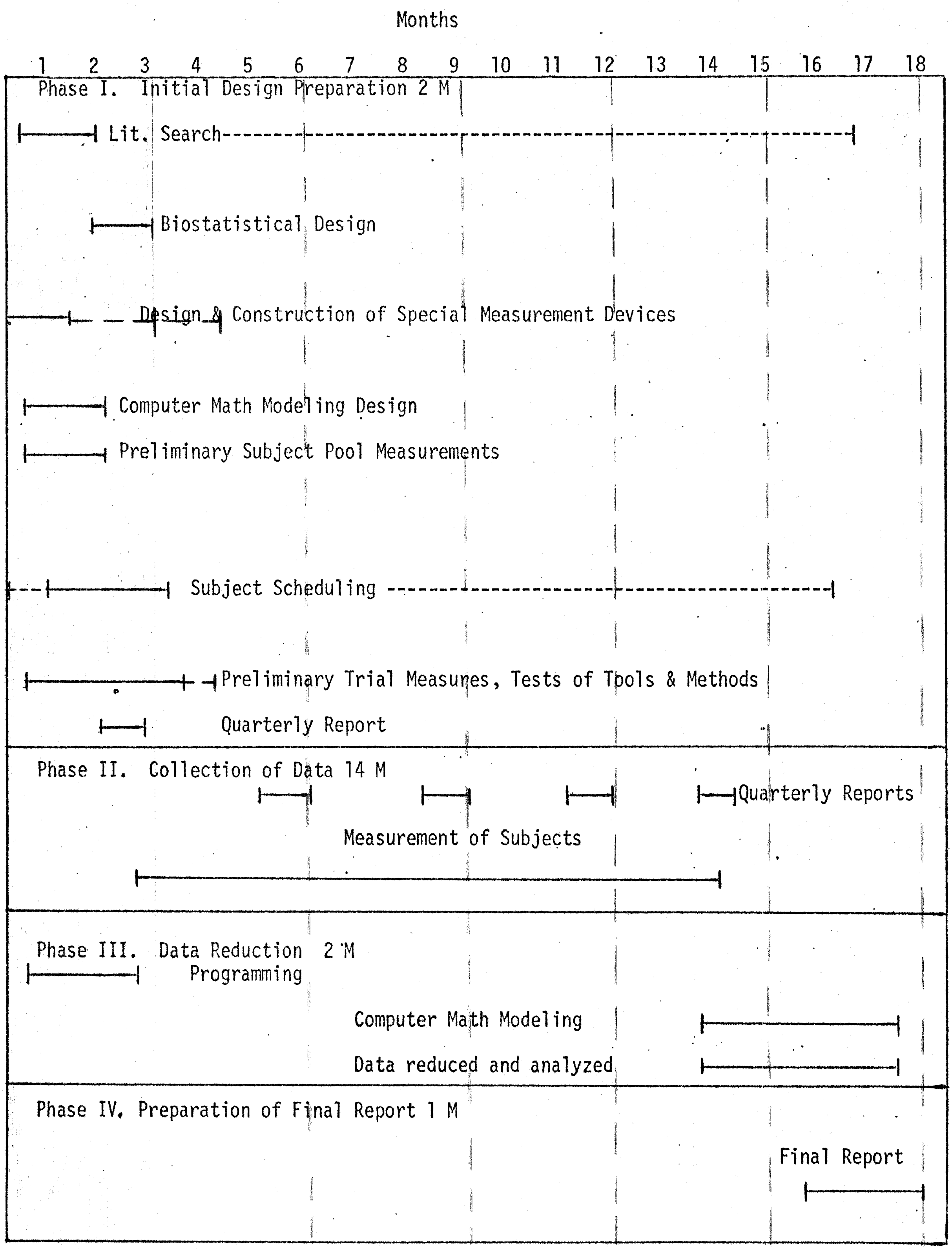
As indicated in Table IX, the first Phase of initial design preparation has now been completed except for installation of the Ampex Recorder and some Cervical Measurement Laboratory equipment on order. Thus this will be extended and emphasis will be on completion of this task. Since trial measures of the EMG, strength, and cervical motion are also dependent upon the equipment it is anticipated that this will take additional time. Two tasks, the literature search, and subject scheduling, will continue into the sixth quarter.

From evaluation of the x-rays taken on subjects to date there is some indication that revision will be required of the scaling method for photogrammetry. By early April the EMG, force, and displacement channels will have been verified, and the headpiece constructed, which will allow verification of the accelerometers as well as definition of the control signals. Some changes in anthropometry, radiography, and the other techniques will undoubtedly result as additional subjects are measured.

The main thrust of the work during the next 90 days will be to complete installation and checkout of equipment and techniques, and initiate subject measurements during Phase II.

TABLE IX

PROJECTED PROGRAM MANAGEMENT



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