AN ANATOMICALLY-VALIDATED METHOD FOR THE ANTHROPOMETRIC PREDICTION OF SEGMENTAL MASSES

by

Michael John Marfell-Jones

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APPROVAL

Name: Michael John Marfell-Jones

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Examining Committee:

Chairman: Dr. J. Dickinson

Dr. W.D. Ross
Senior Supervisor

Dr. N.M.G. Bhakthan

Dr. D. Stirling

Dr. T.W. Calvert
Dean
Faculty Interdisciplinary Studies

Dr. K.M. Bagnall
External Examiner
Faculty of Medicine
University of Alberta

Date Approved: Feb. 13, 1984.

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An anatomically-validated method for the anthropometric prediction of segmental masses.

Author: _____

(signature)

Michael John MARFELL-JONES

(name)

11 April 1984

(date)

CO-PROMOTORS

Professor W.D. Ross, SIMON FRASER UNIVERSITY.

and

Professor Dr. J.P. Clarys, VRIJE UNIVERSITEIT,

BRUSSEL.

ABSTRACT

Conventionally, predictions of segmental masses of the human body are based on the ascription of some percentage of the total body weight. The tactic assumes humans are proportionally similar and have fairly constant segment densities. It was hypothesised that segment anthropometry would yield improved predictions of individual segmental masses in independent samples, whilst also providing an indirect validation of being able to account for total body weight from segmental estimates in disparate *in vivo* samples.

To build anatomical segmentation models, 214 anthropometric measures were repeated bilaterally on three male and three female adult cadavers, prior to surgical dismemberment into 14 segments: head, trunk, arms, forearms, hands, thighs, legs and feet. The limb segments were then fractionated into component skin, adipose, muscle and bone tissues to enable the development of regression equations for the anthropometric prediction of within-segment tissue masses. Obtained measures from the head and trunk and mean bilateral measures from the limbs were used to develop four models for the prediction of the intact mass of each of the 14 segments. These were: a direct regression model, a proportionality/deviation model and two volume-based models. Each of the models was validated against an independent cadaver sample and was shown to be as good as, or better than, the conventional percentage-of-bodyweight approach. The models were then applied to three *in vivo* samples consisting of 896

children, 142 adults and 66 international class bodybuilders. Similar procedures were applied to an available biomechanically-segmented cadaver sample (segmentation at centres of rotation).

Predictions of anatomical and biomechanical segments by the proportionality/deviation and volume-based models were shown by ANOVA for Repeated Measures to be significantly better in accounting for total body weight in children and normal adults than the direct regression approach derived from the same cadaver sample.

Estimations of anatomical and biomechanical segmental masses by the newly delineated models in this study represented improved prediction for both sexes across a wide age and size range and are therefore appropriate for group comparisons.

QUOTATION

"What I liked about chemistry was its clarity surrounded by darkness; what attracted me, slowly and hesitatingly, to biology was its darkness surrounded by the brightness of the giveness of Nature."

- Erwin Chargaff (1978).

Fodio in tenebris.

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I. INTRODUCTION

The purpose of this chapter is to review the historical and current approaches to the prediction of segmental masses and to consider an improved approach to this undertaking.

The search for a practical *in vivo* technique for the measurement or prediction of body segment masses for the purpose of functional analysis has a lengthy history. Over the years, a number of segmental studies have been conducted. Harless(1860), Braune and Fischer(1889), Meeh(1895), Dempster(1955) and Chandler, Clauser, McConville, Reynolds, and Young(1975) carried out studies which resulted in the development of predictive equations based on the assumption of segment weight being a specific percentage of the total body weight.

This approach is only valid under conditions of exact proportionality between any individual and the mean of the sample from which the regression equations were formulated, and assumes a constant density for all segments of the body. Such conditions are patently not applicable across the whole spectrum of human morphology. Extremes of body type are proportionally different to normals (Eiben, 1980; Ross and Ward, 1982). Segments do not display uniform densities (Dempster and Gaughran,1967; Katch and Gold,1976; Clarys, Martin and Drinkwater,1984). Further, the failure of these "percent-of-bodyweight" equations to predict individual segments

well, when applied to alternative cadaver samples, gives cause for concern about their ability to predict segments accurately in any but their estimating sample.

Further, the only *in vivo* check on the prediction of segmental mass involves summing the predicted masses and comparing the sum with the obtained body mass - a technique used by Miller and Morrison (1975). Although this check is only an indication of the accuracy of the prediction and not a true validation, it is not applicable when "percentage of the whole" equations are used, as they predicate equalization. There is, therefore, not even an indication that such predictions are accurate; yet this method has been used widely by functional analysts (Barter, 1957; Whitsett, 1962; Gray, 1963; Hanavan, 1964).

LITERATURE REVIEW

The first investigation of individual segment masses was conducted by Harless (1860) on the bodies of two executed criminals. Harless (1860) dissected the cadavers into 18 major segments and, using sensitive scales and a balance plate, was able to determine the mass and position of centre of mass of each segment. The expression of his segment mass findings (summarised in Table 1.1, along with the findings of other major investigators) initiated the trend to report segment masses as percentages of body weight and encouraged the use of these values as predictors.

Braune and Fischer(1889) performed a segmentation study on 3 adult male cadavers, all suicides. Keeping the cadavers frozen solid throughout the investigation, they used arbitrary cuts across joint centres of straightened limbs. They determined segmental masses and the positions of centres of mass, and also reported the masses as percentages of the total body mass. (See Table 1.1)

Meeh(1894) duplicated Harless' experiments using four infant cadavers. He then used the observed relationships between segment mass and volume (of both his and Harless's work) to compute segment mass from the segment volume of live subjects he had been measuring.

Meeh(1894) departed from the practice of presenting his findings in terms of segments as a percentage of total body weight, (hence his absence from Table 1.1), expressing them only as percent increments of growth, and assumed constant segment density. Despite the dismissal of Meeh's 1894 study by Dempster and Gaughran(1967) as providing "no useful information of a mechanico functional sort",[1] Meeh(1894) is of historical importance since he was the the first to use a volume approach to estimate segmental mass and the first to make a serious attempt to quantify the changes in segment mass during growth and development.

Cleveland(1955), like Meeh(1894), attempted to predict segment weights via volume. He achieved his segment weight

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[1]Dempster and Gaughran(1967), page 35.

values, however, by multiplying segment volumes by total body density - a procedure vulnerable to error as indicated by Harless' (1860) data which highlights the discrepant density values of various segments and the total body.

Table 1.1 Segmental Mass / Body Mass Percentages from Several Cadaver Studies.

Source:	Harless (1860)	Braune & Fischer (1889)	Dempster (1955)	Drillis & Contini (1966)	Dempster & Gaughran (1967)	Clauser et al. (1969)
Sample size:	2	3	8	12	9	13
Segment						
Head & Neck	7.6	7.0	7.9	58.9	7.9	7.3
Trunk	44.2	46.1	48.6		48.4	50.7
Thigh	11.9	10.7	9.7	9.5	10.0	10.3
Leg	4.6	4.8	4.5	4.2	4.6	4.3
Foot	2.0	1.7	1.4	1.3	1.4	1.5
Arm	3.2	3.3	2.7	3.6	2.6	2.6
Forearm	1.7	2.1	1.6	1.8	1.5	1.6
Hand	0.9	0.8	0.6	0.6	0.6	0.7
TOTAL	100.4	99.9	97.5	100.9	97.7	99.7

The first of a series of major segmentation studies this century, from the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base in Ohio, was conducted by Dempster in 1955. Since the focus of the study was biomechanical, Dempster's proposition was that

> links, i.e. the span between joint centers, rather than bones, are the effective core lines of the body segments. Each link is enveloped by a certain mass of adjacent tissue, to form a mass segment. Segments, thus,

must be separated at joint centers.[2]

Consequently, Dempster(1955) followed the lead of Braune and Fischer (1889) in sawing across joint centres when separating two body parts. Whereas Braune and Fischer(1889) cut across the joint centres of straightened limb segments (following freezing), Dempster(1955) endeavoured to fix the joints in a mid-range position, by tying and freezing, before bisecting the joints with cuts through the joint centres.

Prior to dissection, sixty-nine anthropometric measures were taken on each subject in Dempster's(1955) study. Lengths, breadths and girths were measured, but no skinfolds. Dempster's(1955) stated purpose in using cadaver anthropometry was to get an indication of the physical makeup of the cadaver sample and as a check on further measurements made on body segments relating to joint centres and centres of gravity. It may be that the biomechanical emphasis obscured the possible connection between anthropometry and segment mass or that body weight again revealed itself as the best single predictor of segment weight within his sample. Whatever the reason, Dempster(1955) also, chose to report segmental mass/body mass ratios (See Table 1.1) from the 8 cadavers he dissected, to the exclusion of segmental predictors.

In 1957, Barter used the concept of a statistical "Grand Mean" (Barter,1957) to combine Dempster's(1955) data with that of Braune and Fischer(1889), and produced regression equations

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[2]Dempster(1955), page 47.

for calculating segmental mass from total body mass (See Table 1.2).

These regressions were to form the basis of the mathematical models of Whitsett(1962), Gray(1963) and Hanavan(1964), the latter finding widespread use in the area of biomechanical prediction.

Hanavan used an ingenious method to check the accuracy of his mathematical volume prediction. Using data from Dempster's original sample(1955), he divided a segment weight value, obtained from Barter's equations(1957), by the predicted volume to obtain a segment specific gravity which he could then compare with Dempster's experimental finding(1955). This virtually assured the correct segment weight (since Dempster's(1955) sample constituted two thirds of the sample Barter(1957) had constructed his regressions from), and therefore became a test of the accuracy of the volume prediction.

The average results (prediction of segment specific gravity) were

> "within approximately ten percent of the experimental data" [3]

for each segment. Hanavan regarded this as

> "exceptionally good." [4]

This is an important statement by Hanavan(1964), as it is one of the few qualitative statements about the level of prediction in

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[3]Hanavan(1964), page 37.

[4]Hanavan(1964), page 39.

Table 1.2 Regression Equations for Calculating Segmental Mass in Pounds* (from Barter, 1957)

Body Segment	Regression Equation	Standard Error of Estimate
Head, Neck and Trunk	= .47 x T.B.W.# + 12.0	(+6.4)
Total Upper Extremities	= .13 x T.B.W - 3.0	(+2.1)
Both Upper Arms	= .08 x T.B.W. - 2.9	(+1.0)
Forearms plus Hands	= .06 x T.B.W. - 1.4	(+1.2)
Both Forearms$	= .04 x T.B.W. - 0.5	(+1.0)
Both Hands$	= .01 x T.B.W. + 0.7	(+0.4)
Total Lower Extremities	= .31 x T.B.W. + 2.7	(+4.9)
Both Upper Legs	= .18 x T.B.W. + 3.2	(+3.6)
Both Lower Legs plus Feet	= .13 x T.B.W. - 0.5	(+2.0)
Both Lower Legs	= .11 x T.B.W. - 1.9	(+1.6)
Both Feet	= .02 x T.B.W. + 1.5	(+0.6)

T.B.W. - Total Body Weight
$ N=11, all others N=12.
* (Barter, p.6, 1957)

this area.

The adequacy of the volume prediction phase of his model, however, is not the only consideration when the whole model is applied to an <u>in vivo</u> sample. The correct segment weight predictions are of vital importance as they constitute half the

model.

The use of total body weight as a predictor of segment mass is a foundation of Hanavan's(1964) model, with the assumption

> "that the regression equations for segment weights were valid over the spectrum of body weight in the Air Force population"[5]

This is a major assumption on Hanavan's(1964) part (even though Dempster's(1955) sample did come from this population), but he wasn't in a position to be cautioned by Dempster and Gaughran's(1967) warning about predictions generated

> "when records are pooled indiscriminantly" [6]

as later users of his (Hanavan's) model were.

The possible error in using Barter's(1957) equations will be discussed in more detail in Chapter V. When this is compounded by any error in the volume prediction, the accuracy of the overall prediction by Hanavan's model is further diminished.

Nevertheless, Hanavan's(1964) model was the basis for subsequent mathematical models, which have been reviewed by Chandler et al.(1975). These models all used body weight as the predicting variable.

A comprehensive investigation, carried out over a number of years, was published by Drillis and Contini in 1966. They used the method of reaction change, having calculated the position of the centre of mass of each segment by equating it with the

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[5]Hanavan(1964), page 5.

[6]Dempster and Gaughran(1967), page 34.

position of the centre of volume (which they had found by immersion), and developed segmental mass values, expressed, in the usual manner, as percentages of total body mass. (See Table 1.1) However, as was shown by Clauser, McConville and Young(1969), equating the position of the centre of volume and the position of the centre of mass imparts an error of constant direction, the mean value of percent of volume proximal to the position of the centre of mass being 54.9%.

In 1967, Dempster and Gaughran published a reworking of Dempster's 1955 data, (Dempster and Gaughran,1967) supplemented by additional work on an embalmed cadaver and on 11 upper and 41 lower limbs, in 1962. An important feature of this study was the fractionation of each segment into three component tissues (Skin and Fascia, Muscle, and Bone).

The data were reported as percentages of the whole (segment to total body, tissue to total segment) without reference to segment anthropometry. This is probably understandable with regard to the tissues, since Dempster and Gaughran's(1967) purpose in fractionating the segments was to compare the densities of the different tissues and not examine anthropometric concomitants. However, it would appear clear from the report that Dempster and Gaughran(1967) saw precise dissection technique as being the most important factor in developing useful predictive equations and nothing fundamentally wrong with the "percentage of the whole" approach.

In 1967, Bernstein published a summary statement of work he had conducted in Russia in the 1920's. After analysing the results of measurements taken on 152 subjects (using the modified Borelli apparatus and the method of reaction change (outlined by Miller and Nelson,1973) to predict mass and centre of mass of segments) Bernstein concluded that the individual variation was so great that

> either we may resign ourselves to measuring with the complex techniques we have developed (as mentioned above) every new subject with whom we deal - or we may attempt to find such anthropometric and structural correspondence (correlations) as will enable us to determine with sufficient accuracy the probable radii of our subjects on the basis of their general habits and anthropometric data[7]

Bernstein(1967) appears to have been the first to suggest anthropometric and structural correspondence in segments, but was unheeded for many years. Segmental parameters were not used in a predictive model until Clauser et al.(1969).

The second major segmentation study this century was conducted by Clauser et al.(1969). That Clauser et al.(1969) recognised the value of Bernstein's(1967) advice is clear from their use of Bernstein's(1967) quote. The conclusion of Clauser et al.'s(1969) introduction set the stage for a significant advance in the area of segment mass prediction.

> Of primary interest is whether or not body segment parameters can be predicted with any degree of accuracy from anthropometric dimensions. If this can be answered in the affirmative, then it would be important to know if such predictions provide sufficient accuracy for estimating parameters for individuals as well as for the

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[7]Bernstein(1967), page 13

corresponding populations.[8]

Data, consisting of 99 anthropometric variables, total body volume and the position of the total centre of mass, and the mass, volume and position of the centre of mass for each of 14 segments, were gathered on 13 male cadavers and stepwise regression equations were developed for the prediction of segmental mass from anthropometric measurements including total body mass. Clauser et al.(1969) followed Dempster's(1955) protocol where possible, though when the tissue would not stretch sufficiently to permit flexion to the mid-range position they did not sever it to facilitate such flexion (as Dempster(1955) had done).

Although total body mass turned out to be the single most important variable in predicting segment mass, Clauser et al.(1969) found the inclusion of 2 or 3 segment-specific anthropometric variables in the equations decreased the magnitude of any segmental weight prediction error. His penultimate sentence in the conclusion of his report

> "The predictive equations developed in this study are believed to provide a better estimate of weight and location of the center of mass of segments of the body for individuals and populations than were previously available."[9]

indicates a positive result from the investigation. Their final sentence

> "They should not, however, be considered as other than good first approximations until they can be adequately

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[8]Clauser et al.(1969), p.17.

[9]Clauser et al.(1969), page 61

validated on live populations."[10]

was a wise caution. The inclusion of body weight as the major predictor in all segments except the forearm, hand and leg, precludes the use of even the indirect check - accounting for total body weight by summing the predicted segment weights. Their regressions, are shown in Table 1.3.

The third and most recent dissection study was that of Chandler et al.(1975) in which six male cadavers were segmented. The regression equations generated to predict segment mass used total body weight as the predicting variable. The purpose of this study was to provide

> "empirical values against which the moments of inertia of various geometric shapes and sizes may be tested."[11]

and the authors only gave the regression equations for the convenience of the reader to document the relationships for their particular cadaver sample.

One feature of this study was the complementary investigation of the use of stereophotometry to predict segment volumes (Herron et al. 1976). This technique was subsequently utilised by McConville et al.(1980) on 31 male subjects in vivo. The reported regressions predicted segment volumes from stature and total bodyweight. Application of the regressions to Clauser et al.'s(1969) sample (and input of that sample's mean segment densities) did not give good segmental prediction, yet displayed an extremely small variance in accounting for total body weight.

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[10]Clauser et al.(1969), page 61.

[11]Chandler et al.(1975), page 100.

Table 1.3 Regression Equations for Predicting Segmental Weight in kilograms (from Clauser et al.,1969).

Head	Head Circ	Weight(kg)		Constant	R	SE Est
	0.148			-3.716	.814	0.20
	0.104	+0.015		-2.189	.874	0.17
Trunk	Weight(kg)	Trunk Length	Chest Circ			
	0.551			-2.837	.966	1.33
	0.494	+0.347		-19.186	.979	1.11
	0.349	+0.423	+0.229	-35.460	.986	0.92
Upper Arm	Weight(kg)	Arm Circ(ax)	Acrom-Rad Length			
	0.030			-0.238	.879	0.14
	0.019	+0.060		-1.280	.931	0.12
	0.007	+0.092	+0.050	-3.101	.961	0.09
F/Arm	Wrist Circ	Forearm Circ				
	0.119			-0.913	.827	0.09
Hand	Wrist Circ	Wrist Br/Bone	Hand Brdth			
	0.051			-0.418	.863	0.03
	0.038	+0.080		-0.660	.917	0.03
	0.029	+0.075	+0.031	-0.746	.942	0.02
Thigh	Weight(kg)	Upper Thigh Circ	Iliac Crest Fat*			
	0.120			-1.123	.893	0.54
	0.074	+0.138		-4.641	.933	0.45
	0.074	+0.123	+0.027	-4.216	.944	0.43
Calf	Calf Circ	Tibiale Ht	Ankle Circ			
	0.135			-1.318	.933	0.14
	0.141	+0.042		-3.421	.971	0.09
	0.111	+0.047	+0.074	-4.208	.979	0.08
Foot	Weight(kg)	Ankle Circ	Foot Length			
	0.009			+0.369	.810	0.06
	0.005	+0.033		-0.030	.882	0.05
	0.003	+0.048	+0.027	-0.869	.907	0.04

*Iliac Crest Fat(mm) = 0.78 Skinfold.Iliac Crest(mm) - 0.27; weight is kg; all other dimensions are in cm.

This result confirms the preclusion of accounting for total bodyweight as any sort of validation check, there being a spurious correlation between the dependent and the independent variables.

The question could well be asked why the use of body weight as a segment weight predictor has been accepted for so long. This has most likely been so because, in the cadaver samples studied, body weight was the best single predictor. In addition it is a very convenient predictor - easy to measure and seldom not measured in any *in vivo* sample.

Reliance on the use of a set relationship between segmental mass and total body mass, however, fails to accommodate those individuals whose proportions differ from the samples used to identify those relationships. As Miller and Nelson(1973) pointed out, such computational methods were derived from a limited number of Caucasian adult male cadavers. Thus investigators should always be cognizant of this limitation, particularly with populations which may be different from the original sample in terms of age, sex, race or body composition.

Unfortunately, due to the complexity, size and cost of a cadaver research expression, there appears to be no way around Miller and Nelson's(1973) caution, and sample specificity may still be a factor in the results until such time as a large enough sample segmented by identical technique has been aggregated.

The problems associated with successful prediction in this area are many. Yet the task is there to be mastered.

If an *in vivo* technique could be developed which did not incorporate total body mass as one of the predictor variables in the calculation (thereby permitting its use to validate that the sum of the parts is equal to the whole), and took into account differences in proportionality, then segmental mass predictions could be made with greater confidence in all subjects regardless of age, sex or morphology.

EXPERIMENTAL HYPOTHESIS

Segmental mass is governed by the volume of the segment and its density. The density is governed by the relative constituency of the segment, i.e. how much adipose tissue, muscle, skin, bone and residual it contains, and the density of each of those components.

Anthropometry currently can not reveal differences in density within the same component tissue, for it only measures size, but it can tell us about the relative amounts of each tissue within the segment. The following questions can be posed.

1. Will the size of the skinfold reveal something about the amount of adipose tissue in the segment?
2. Will the size of the skinfold-corrected girths disclose information about the muscle?
3. Will the lengths and breadths between distinguishable bony landmarks give insight into how much bone is present?

If we can incorporate these factors in a model, can we come closer to the true prediction of segment weight?

My hypothesis, therefore, was that

> Differences in segmental anthropometry will reflect differences in segment composition giving a better prediction of segment mass than a prediction based on a percentage of body weight.

RESEARCH PROPOSAL

The aim of this study was to test this hypothesis by developing three models which predict segment masses from segment-specific anthropometric variables. The models could then be applied to at least three *in vivo* samples; compared, on the basis of their ability to account for total body weight; and the best model chosen for the prediction of segmental masses for comparative purposes in a wide range of individuals.

MODEL DEVELOPMENT

Regression (REG) Model

The first model would be a straight regression of intra-segmental anthropometry against segment mass, based on an estimating sample.

$$Y = A1*X1 + (A2*X2 +) C$$

where: Y is segment mass
X1 and X2 are segment lengths or girths.

This would establish the best relationship between anthropometry and segment mass for the sample, though possibly at the risk of

an increased sample specificity.

Proportionality/Deviation(P/D) Model

In 1974, Ross and Wilson devised a unisex Phantom which serves as a reference model for proportionality comparisons of subjects, regardless of age, sex or race. The Phantom Stratagem expresses anthropometric values as z-values which are height-(or any other parameter) adjusted deviations from the Phantom value for the particular variable.

The principle of expressing scores in terms of standard deviations from a known reference value was further developed by Drinkwater and Ross (1980) in their tactic for the fractionation of body mass into four components, viz. adipose tissue, bone, muscle and residual. In this tactic, the mean deviation of a set of predictor variables is said to reflect the deviation from a reference mass for each of the four components. The tactic is validated by the sum of the four predicted component masses equalling the observed total body mass.

The same principle can be applied to the prediction of segmental masses. An example, using a single predictor variable for simplification, serves to illustrate this principles.

Let the reference values for forearm length and segment mass be as follows:

Variable	Mean	Standard Deviation
Forearm Length	22cm	2cm
Forearm segment mass	1kg.	0.1kg.

The principle predicates, therefore, that a subject whose forearm is 24cm long (one length standard deviation above the reference) would have a segmental mass of 1.1kg (one mass standard deviation above the reference). If shape and composition were constant for specific segments, a single predictor would be sufficient to predict in all cases. However, since there are individual differences, a battery of variables is needed to reflect the different tissue contributions.

$$ZSEG = (A1*ZX1 + A2*ZX2 + ..+ An*ZXn) / n$$

where: ZSEG is segment mass
expressed in Phantom mass
standard deviations.
ZX1 and ZX2 etc. are
segment lengths or
girths expressed in

Phantom variable
standard deviations.
"n" is the arithmetical
divisor which ensures
that identical Phantom
z-values for each of the
predicting parameters
would give an identical
mean z-value for the segment.

The second model would predict segmental mass based on the deviation of intra-segmental anthropometry from the reference anthropometric values of the Phantom of Ross and Wilson (1974).

Volume-Based (VOL) Model

Both the regression and P/D models were based on the prediction of mass, for each segment, directly from the measured variables. However, since the prediction of volume has been the commonest approach used in mathematical segment models, an improved approach to mass might be made through volume. Therefore a third model was hypothesised which regressed the derived variable of a girth squared times the length, for a segment, against the segment mass.

$$Y = A1*((X1)**2)*X2 + C$$

where: X1 is a segment girth

X2 is a segment length.

CADAVER DISSECTION

The focus of nearly all of the investigators who have conducted cadaver segmentation studies has been a biomechanical one. Their main aim has been the *in vivo* prediction of mass and centre of mass of various segments. Dempster(1955), Clauser et al.(1969) and Chandler et al.(1975) also measured the moments of inertia of each segment as a further aid to biomechanical analysis.

A crucial feature of dissection with the above focus is the selection of the cutting plane when severing body parts. The practice of dissection unidirectionally through joint centres, which facilitates some biomechanical analyses, appears to create some anomalous situations in terms of the allocation of various tissues to various segments. For example, the joint centre at the knee is on a line between the maximum protrusions of the medial and lateral epicondyles of the femur. Biomechanical severance at this joint centre leaves major portions of the femoral condyles associated with the leg segment and the patella divided between the leg and thigh segments.

Discussion of this situation with a biomechanist (Chapman,1982), led to the conclusion that the various cuts

could well be made on the line through the joint centres, but only as far as the soft tissue was concerned. The bone ends could then be circumscribed leaving the bones intact in the segment wherein their major portion lay. All parts of the femur, for example, would then be allocated to the thigh segment (as would the whole of the patella). This technique had at least a part precedent as it had been used at the shoulder and hip by Harless(1860), though he segmented the more distal joints by unidirectional cuts through bony condyles.

A third technique has been pioneered by Grand (1977) during the course of some three thousand dissections on over eighty different species. Grand's(1977) approach is to cut individual muscles at their origin or insertion and assign them to one side or another of the joint. The assigning is generally based on all parts of a muscle going to the segment wherein lies the majority of its mass (c.f. Chapman's suggestion above, with regard to the bone allocation.). Grand's(1977) rationale is that this facilitates comparison of completely intact muscle groups in corresponding segments of different animals. He feels that the method is no more arbitrary than the joint-centre method of Dempster(1955) since

> "the mammalian body does not lend itself to simple geometrical segmentation." [12]

In 1979, a co-operative dissection study was initiated by Dr W.D. Ross of Simon Fraser University(SFU) and Dr J-P Clarys

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[12]Grand(1977), page 214.

of Vrije Universiteit, Brussel(VUB). The study evolved into, perhaps, the most comprehensive cadaver analysis study ever undertaken. Clarys and two Simon Fraser investigators, Martin and Drinkwater, conducted the research in Brussels in 1979/80. Twenty seven cadavers were completely fractionated into five components (skin, adipose tissue, muscle, bone and residual) following extensive anthropometry, and each component was weighed in air and in water.

Since the above study was not specifically investigating segmental parameters, no attempt was made to follow a segmental approach within the limbs. For example, all the adipose tissue for the whole of the upper limb was combined, no differentiation being made between that from the hand and that from the arm or forearm.

The limbs, in toto, were segmented from the trunk according to a set protocol, however. A vertical cut was made at the shoulder, with circumscription of the humeral head, to detach the upper limb, and a sinuous cut was made from the iliac crest to the ischium, circumscribing the femoral head, to detach the lower limb proximal to the gluteal muscles.

In order to facilitate maximum future use of the already available data from the main VUB study and to avoid sectioning any bones, it was decided to use a modification of the second technique in the six cadavers (3 male and 3 female).

The modification consisted of severing the segment at the joint space, along a single plain as far as the soft tissues

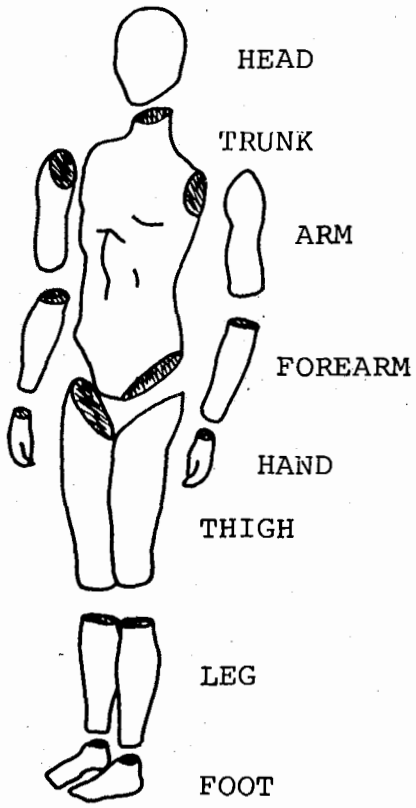
were concerned, and circumventing any bony parts where they protruded across the plane of the cut.

It was decided that the cadaver research would entail measurement, segmentation and further measurement on cadavers available at the Instituut voor Morphologie, Vrije Universiteit, Brussel, Belgium. The dissection data assembly would be supervised in Brussels by Professor Dr. J-P. Clarys, of the Faculty of Medicine.

Each cadaver would be weighed, first in air and then underwater. Repeat measures would be taken bilaterally as discussed in Chapter II.

Each cadaver would be segmented into fourteen parts - head, neck and trunk, two each of: thigh, leg, foot, arm, forearm, hand, (also as outlined in Chapter II). Figure 1.1 depicts the general segment divisions.

Figure 1.1 Anatomical Segments.



PREDICTION OF SEGMENT TISSUE MASSES

Dempster(1955) dissected a single cadaver into tissue components and Dempster and Gaughran(1957) fractionated seven cadavers into skin and fascia, muscle and bone. However, as discussed earlier in the chapter, the data were only reported as percentages of total segment weight and not related to segmental anthropometry.

Since the main thrust of the thesis necessitated cadaver dissection it was decided not to miss the opportunity to complement the work of Clarys et al.(1984) and fractionate each of the individual limb segments into its four constituent components.

The trunk and head segments would not be fractionated, as sufficient manpower was not available to complete such an undertaking. In addition, duplication of the hip and shoulder segmentation technique used by Clarys et al.(1984) meant that fractionation data was already available on the trunk and head.

Each segment would be weighed in air and water. The limb segments would then be fractionated into four components, viz. skin, adipose tisue, muscle and bone.

BIOMECHANICAL MODEL DEVELOPMENT

At the time of the setting up of the research phase in Belgium, correspondence was initiated with Charles E. Clauser at the Wright-Patterson Air Force Base in Ohio. Immediately before departing Simon Fraser for Brussels, the author was honoured with a tape from Ohio containing all the raw data from Clauser et al.'s 1969 study.

As a result of this generosity, it was decided to develop a second set of prediction models, parallel to those proposed above, based on Clauser et al.'s(1969) sample, which would predict the masses of biomechanical or 'link' segments. (Since

Clauser et al.'s(1969) segmentation had had a biomechanical orientation.) Thus the study would provide optional models, the choice of which would depend on the definition of the segment desired to be predicted.

APPLICATION AND TESTING OF MODELS

Each model would be applied to its estimating sample to examine its prediction accuracy. Each model would then be applied to three *in vivo* samples:

896 children aged 5 to 19. This sample was measured by the Simon Fraser Anthropometric Research Unit in 1978 and is described in data summarised by Ross et al.(1980) and Ross and Marfell-Jones(1982).

142 college adults. This sample was measured at Simon Fraser University by the author and other members of the Kinanthropometric Research Unit between 1980 and 1983. It consisted of 80 females and 62 males who were taking Kinesiology courses, but were not specifically Kinesiology Majors.

66 international bodybuilders. This sample was measured in 1982 by W.D. Ross and J. Borms in Cairo at the World Amateur Bodybuilding Championships.

In each of these *in vivo* samples, the sum of the predicted segment masses would be compared to the observed body weight, and the discrepancy expressed as a percentage. This percentage

discrepancy value would serve as the value for comparison between models.

The criterion for the acceptance of each model would be based on its ability to:

1. predict individual segment weights in its own cadaver sample
2. account for total body weight, when applied to *in vivo* samples,

better than previously-accepted models.

Differences in predictive ability between models would be identified by application of the Repeated Measures Test (Hull and Nie, 1981), described by Harris (1975), to individual percentage discrepencies. These would be confirmed by application of the Friedman Test (Hull and Nie, 1981), described by Conover (1971). The statisical significance of any superiority demonstrated by the best predicting model would then be re-examined by the Repeated Measures Test using contrasts to compare this model with any other, individually.

True validation of each model is not really possible since the technique discrepancy results in raw data only being available in one sample for each technique. (Dempster (1955) and Dempster and Gaughran (1967) see technique uniformity as crucial to any comparison or combination of samples.) However, an indication can be obtained of the accuracy of the models in predicting segment mass by applying the anatomical models to the biomechanical sample, and vice versa, taking cognisance of the technique discrepancy.

Therefore, each model should also give a reasonable prediction of individual segment mass in the parallel cadaver sample.

In addition, the models would be applied to the main Cadaver Analysis Study(CAS) sample (Clarys et al., 1984) and tested on their ability to predict the combined trunk and head segments and the total upper and lower limb segments.

DEFINITIONS

The terms "mass" and "weight" have been used synonymously so far. The semantic difference between the two is that weight is derived from mass by multiplying by gravity. Since anthropometry is not thought to change to any measurable extent by a change in gravity, then the parameters being predicted by the models are actually masses. However, observed body weight is a factor in a) the indirect validation and b) much of the discussion, so it would be inappropriate to refer to mass in this context. Similarly, the whole-segment parameter measured in the cadaver sample was weight not mass. Reports in the literature do not make this distinction between segment mass and segment weight. It would be unnecessarily confusing to do so. The term "mass" will be generally used in this study, but the term "weight" will be used in the context of the literature.

Two distinct segmentation techniques are considered in this

study:

1. The technique employed by the author (considered first at each stage throughout the study), involving segmentation through joint spaces, will be known as the ANATOMICAL segmentation technique.
2. The technique employed by Clauser et al.(1969), involving segmentation through joint centres of rotation, will be referred to as the BIOMECHANICAL segmentation technique.

There will be two estimating cadaver samples:

1. That segmented by the anatomical technique will be known as the MiniCAS(MCAS) sample, as it was a smaller continuation of the Cadaver Analysis Study(CAS) of Clarys et al.(1984). Models estimated from this sample will predict anatomical segment masses and their names will be prefixed by the initials MC.
2. That segmented by the biomechanical technique, will be known as the CLAUSER(CL) sample. Models estimated from this sample will predict biomechanical segment masses and their names will be prefixed by the initials CL.

There will be three types of model:

1. That which regresses segment anthropometry against segment weight will be known as the REGRESSION(REG) model. Models of this type will contain the initials REG in the centre of their name.
2. That which predicts segment mass as a deviation from a reference mass will be known as the PROPORTIONALITY/DEVIATION(PD) model. Models of this type will contain the initials PD in the centre of their name.
3. That which predicts segment mass by way of segment volume will be known as the VOLUME-BASED(VOL) model. Models of this type will contain the initials VOL in the centre of their name.

There will be six testing samples:

1. Models applied to the anatomical cadaver sample(MCAS) will be designated with the initials MC as a suffix.
2. Models applied to the biomechanical cadaver sample(CL) will be designated with the initials CL as a suffix.
3. Models applied to the main Brussels cadaver sample(CAS) will be designated with the initials CAS as a suffix.
4. The child sample will be known as COGRO(CO). Models applied to this sample will be designated with the initials CO as a suffix.
5. The college sample will be known as NEWADULT(NA). Models

applied to this sample will be designated with the initials NA as a suffix.

6. The bodybuilder sample will be known as BODYBUILD(BB). Models applied to this sample will be designated with the initials BB as a suffix.

For example:

MCPDBB will indicate a PROPORTIONALITY/DEVIATION model, estimated from the MiniCAS sample, which predicts (anatomical) segment mass in the BODYBUILDER sample.

CLVOLCO will indicate a VOLUME-BASED model, estimated from the CLAUSER sample, which predicts (biomechanical) segment mass in the COGRO sample.

This study has addressed itself at length to the situation of using percentages of total body weight to predict segment mass, and the unavailability in this situation of the indirect check of accounting for total body weight. When the dependent variable in a regression equation is comprised of part or all of the same variable as the independent variable, there is a spurious relationship between the two. In this study, the word 'spurious' denotes such a relationship.

Two terms will be used in making evaluations of the predictive abilities of the models considered in this study. These terms are:

1. 'Acceptable'. This term will be used:
   a. For absolute predictions - when 95% of the individual segments are predicted within 15% of their true value. (This was based on a value intermediate to the "acceptable" prediction of 95% within 20% of Barter(1957) and the "exceptional" prediction of half within 10% of Hanavan(1964).)
   b. For comparative predictions - when there is no statistically significant difference at the 0.05 level between the predictive ability of the model and its comparator.
2. 'Good'. This term will be used:
   a. For absolute predictions - when 95% of the individual segments are predicted within 10% of their true value.
   b. For comparative purposes - to describe the predictive ability of a model whose prediction is statistically significantly better than its comparator at the 0.01 level.

ERRORS AND ASSUMPTIONS

Whereas the use of cadavers to construct segmental prediction overcomes the problem of prediction validation within

the sample, it raises the question immediately of the validity of applying the relationships found in such a sample to the living.

Todd and Lindala(1928) used preservative to restore the tissue to "normal" appearance in fifty white male cadavers (in the course of investigating post mortem changes in tissue thickness). They found that the amount of preservative used markedly affected circumferential measurements. In his 1955 study, Dempster used seven unpreserved cadavers and one embalmed cadaver. He made no distinction between the two conditions in measuring or reporting. In a personal communication to Clauser et al. (1969), Dempster wrote:

> "Preserved specimens, which look natural, have in all probability, a weight and volume similar to that which they had at death."[13]

Fujikawa(1963) used four preserved and one fresh cadaver. He observed:

> "little influence of the injected formalin-alcohol about the ratio of weight of each part to the body weight and little individual difference of the physique" [14]

and also made no differentiation between the cadaver types.

Clauser et al.(1969) used thirteen embalmed cadavers. They injected a solution (approximately three gallons) containing equal proportions of phenol, glycerine and alcohol by gravity flow through the subclavian and femoral arteries. They observed that:

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[13]Clauser et al.(1969), page 18.

[14]Fujikawa(1963), page 124.

> "the preservative is not retained in the quantities injected for any appreciable time....the tissue appearing only to retain the amount needed to replace body fluids lost through the skin immediately post mortem." [15]

This finding answers the question raised by Todd and Lindala(1928) concerning the cruciality of the amount of preservative injected. Clauser et al.(1969) concluded that:

> "cadavers, if properly treated, will be closely comparable, in mass distribution and density, to living subjects...(and)...use of preserved specimens is not believed to have introduced a significant bias in the results obtained." [16]

If there are changes in circumferences and segment composition, these changes should be detectable anthropometrically. The relationships should not change to any marked extent, only the absolute values. It is a major assumption of this study, therefore, that the relationship of anthropometry to segment composition in cadavers is similar to the relationship of anthropometry to segment composition in the living.

Based on the work of the above authors, it appears that embalmed cadavers can be used to approximate these relationships in the living. It is a further assumption that the use of embalmed cadavers, as opposed to fresh cadavers, will not appreciably affect the predictive ability of the models generated. This assumption was further reinforced by the use of embalmed cadavers by Chandler et al.(1975) and Clarys et

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[15]Clauser et al.(1969), page 18.

[16]Clauser et al.(1969), page 18.

al.(1984).

RESEARCH DESIGN SUMMARY

The research design was summarised as follows:

1. Segment a cadaver sample using the anatomical segmentation protocol.
2. Build three models estimated from this sample, to predict anatomical segment masses. These would be
   a. A straight regression model of anthropometry predicting segment weight.
   b. A proportionality/deviation model predicting segment weight as a deviation from a reference segment weight paralleling the anthropometric deviation from reference anthropometric values.
   c. A volume-based model of anthropometry predicting segment mass based on predictor variables associated with volume, i.e. a squared girth times a length.
3. Build three parallel models based on the cadaver sample of Clauser et al.(1969), Wright-Patterson Air Force Base, Ohio. These models would predict biomechanical segment masses in accordance with the technique used by Clauser et al.(1969) to segment their subjects.
4. Validate each model by applying it to an independent cadaver sample.

5. Evaluate each model by applying it to:

   a. The cadaver sample from which it was estimated.

   b. Each of three *in vivo* samples:

      1) 896 children aged 5 to 19 (COGRO).

      2) 142 college adults (NEWADULT).

      3) 66 international bodybuilders (BODYBUILD).

The thesis, therefore, would investigate and provide

1. viable models for the prediction of both anatomical and biomechanical segment mass from segmental anthropometry.
2. equations for the prediction of segmental tissue masses from anthropometry.

II. METHODS

This chapter describes fully the anatomical cadaver dissection phase of this study.

The anatomical phase of the research was carried out in the Department of Anatomy in the Instituut voor Morphologie, Vrije Universiteit Brussel(VUB), Brussels, Belgium. The dissection team consisted of six technicians from the department and eight medical students, directed and led by Dr. J.P. Clarys and the author.

The cadavers were obtained via the testament system in operation at VUB. This system permits donation of a body either by a subject prior to demise or post-demise by the executors. It has been operated successfuly in Brussels for a considerable period with both legal and social approval.

The six cadavers dissected were selected from a total of seventeen embalmed cadavers stored on stainless steel trays (for periods varying from one to two years) in cool storage at 3 degrees Celsius within the department. Selection was on the basis of overall physical appearance and the general absence of wasting, except in the case of Subject 1, who was deliberately selected to increase the heterogeniety of the sample.

Embalming had been carried out originally within 48 hours of demise by the infusion under pressure of approximately 6 litres of embalming fluid via either the tibial or carotid

artery. Three female and three male cadavers (See Table 2.1) were measured and dissected. The effects of embalming and the necessary assumptions concerning this type of material have been discussed in Chapter I. Basic data on the subjects are shown in Table 2.1.

Subjects 1, 5 and 6 died of age-associated heart failure. Subject 4 died of a drug overdose. The cause of death of subjects 2 and 3 was not known at the time of dissection.

Each cadaver was suspended overnight to raise its temperature from that of the chilled storage room to room temperature (approximately 17 degrees Celcius), and to permit the tissues to regain their former shape following the lengthy period of supine lying which invariably had the effect of flattening the posterior aspect of the whole body. Heat lamps were applied to assist the raising of the temperature. The research procedure was then carried out over a two day period according to the sequence shown in Table 2.2.

On the 1st day the cadaver was marked and a battery of 214 anthropometric measures was repeated bilaterally. The intact cadaver was then weighed in air and water. All the anthropometric measurements were made by the author with the aid of an assistant to record data.

On the second day the full dissection team assembled early in the morning. The cadavers were segmented and each segment was weighed both in air and under water. Individual limb segments were then allocated to members of the research team who

Table 2.1 "Basic Data for the Six Cadavers".

Subject	Sex	Age at Demise (decimal years)	Suspended Length (cm)	Supine Length (cm)	Body Weight Before Dissection (gm)
1	M	69.3	172.00	169.6	43600.0
2	M	78.5	162.30	161.3	66300.0
3	F	79.5	149.00	148.5	50900.0
4	M	16.0	179.30	178.4	80100.0
5	F	79.1	151.50	149.9	49000.0
6	F	79.9	165.00	162.0	55750.0
MEAN		66.7	163.2	161.6	57608.3
S.D.		25.1	11.7	11.4	13418.0

Table 2.2 "Cadaver Measurement, Segmentation and Fractionation Schedule."

Day 1.	Whole body and segmental anthropometry. Whole body weighing in air and under water.
Day 2.	Whole body weighing in air. Segmentation into 14 segments. Weighing in air and water of whole segments. Removal of skin and subcutaneous adipose tissue. Lean body anthropometry on individual segments. Continued fractionation of segments into component tissues. Weighing of tissues for each segment in air and under water. Osteometry.

dissected them into skin, adipose tissue, muscle and bone components. Each component was then weighed in air and under

water. This procedure continued throughout the day until all the segments had been completely fractionated and weighed. Usually this was achieved within 12 hours. Osteometric measurements were then taken on the limb bones.

ANTHROPOMETRY

Preparation.

The anthropometric training and mastery of technique was part of the ongoing preparation of the author within the Kinesiology Graduate Program at Simon Fraser University. This consisted of constant measuring practice and data collection over a period of two and a half years from September 1980. In that period, the author measured 157 individual subjects unaided and also measured 217 further subjects as a member of variuos measurement teams. Specification of landmarks and discussion of technique nuances were summarised as part of this experience. This summary has been reported as standards in Ross and Marfell-Jones(1982). Further, the author measured 32 macaques at Simon Fraser University and five macaques at the Oregon Regional Primate Center. Under the guidance of Dr T.I. Grand, four of the macaques were dissected at the Center to establish the segmentation techniques employed in this study.

Measurement Selection.

The selection of anthropometric measurements was based on three criteria:

1. All those measures taken by Clauser et al. (1969).
2. All those measures taken by Clarys et al. (1984), which included analagous measures to the *in vivo* measures described by Ross and Marfell-Jones (1982).
3. Additional measures not taken by either of the above which were thought to provide further information about segmental size, shape and composition, e.g. metacarpal and metatarsal depth.

MARKING OF SUBJECT

The anthropometry was preceeded by the marking of the subject. The cadaver was marked at the sites listed below either by a cross to indicate a particular point or by a line to indicate a girth. Limb girth sites were completely circumscribed by a line at right angles to the long axis of the particular body part.

The definitions of anthropometric landmarks and intermediate sites are given with the measurement definitions in Appendix 1. Anatomical landmarks are self defined. The sites marked were:

Acromiale
Radiale
Lateral Epicondyle of the Humerus
Medial Epicondyle of the Humerus
Tip of the Olecranon Process
Stylion
Metacarpale III
Cervicale
Axillary trunk girth
Mesosternale
Xiphion
Ilio-spinale
Trochanterion
Tibiale Laterale
Tibiale Mediale
Malleolare Externus
Malleolare Internus
Metatarsale III
Axillary arm girth
Triceps site
Triceps girth
Biceps site
Minimum arm girth
Elbow girth
Maximum forearm girth

Maximum forearm site
Mid forearm girth
Mid forearm site
Bi-stylion girth
Upper thigh girth
Mid thigh girth
Anterior thigh site
Medial thigh site
Posterior thigh site
Maximum calf girth
Medial calf site
Mid calf girth
Minimum ankle girth

Though it is obvious from the above list that a considerable number of marks were made on the cadaver, this saved a great deal of time, during the measurement phase, in locating the exact measurement site.

REFERENCE DISTANCES

To enable corresponding lean body and osteometric measures to be made at approximately the same points on the limb, the distances between the sites of these measures and some easily distinguishable bony landmark were measured at the time of marking the cadaver. The reference distances were:

Arm

Axillary fold to medial epicondylar humerus
Triceps site to lateral epicondylar humerus
Minimum arm girth site to lateral epicondylar humerus

Forearm

Maximum forearm girth site to olecranon tip
Mid forearm girth site to olecranon tip
Proximal wrist girth site to stylion

Thigh

Upper thigh girth site to medial epicondylar femur
Mid girth site to medial epicondylar femur

Leg

Maximum calf girth site to tibiale laterale
Mid calf girth site to tibiale laterale
Minimum ankle girth site to malleolare externum

MEASUREMENT

Following the marking of the subject, anthropometric measures were taken. These consisted of skinfolds (by two different types of caliper), girths, direct lengths, breadths and depths. All measures, except those specifically mentioned, were made with the cadaver suspended from the ceiling by a head harness. A total of 182 different variables were repeat-measured on each subject. The mean of the two measures was accepted as the value for that parameter. Where the second measure did not approximate the first, a third, and if necessary a fourth, measure was taken. The specifications for each of the anthropometric measurements are given in Appendix 3.
All head measurements were made in the supine position as the

head harness precluded measurements whilst suspended. Although not indicated on the lists, measurements were made bilaterally, except where there was only one, e.g. chest girth.

The anthropometric instruments are shown in Appendix 2.

INSTRUMENTATION

Measurements were made using the appropriate instruments as shown in Figure 2.1.

These were:

Martin Anthropometer (a)

(with baseplate) (b)

Slimguide Skinfold Caliper (c)

Anthropometric Tape (d)

Widespreading Caliper (e)

Harpenden Skinfold Caliper (f)

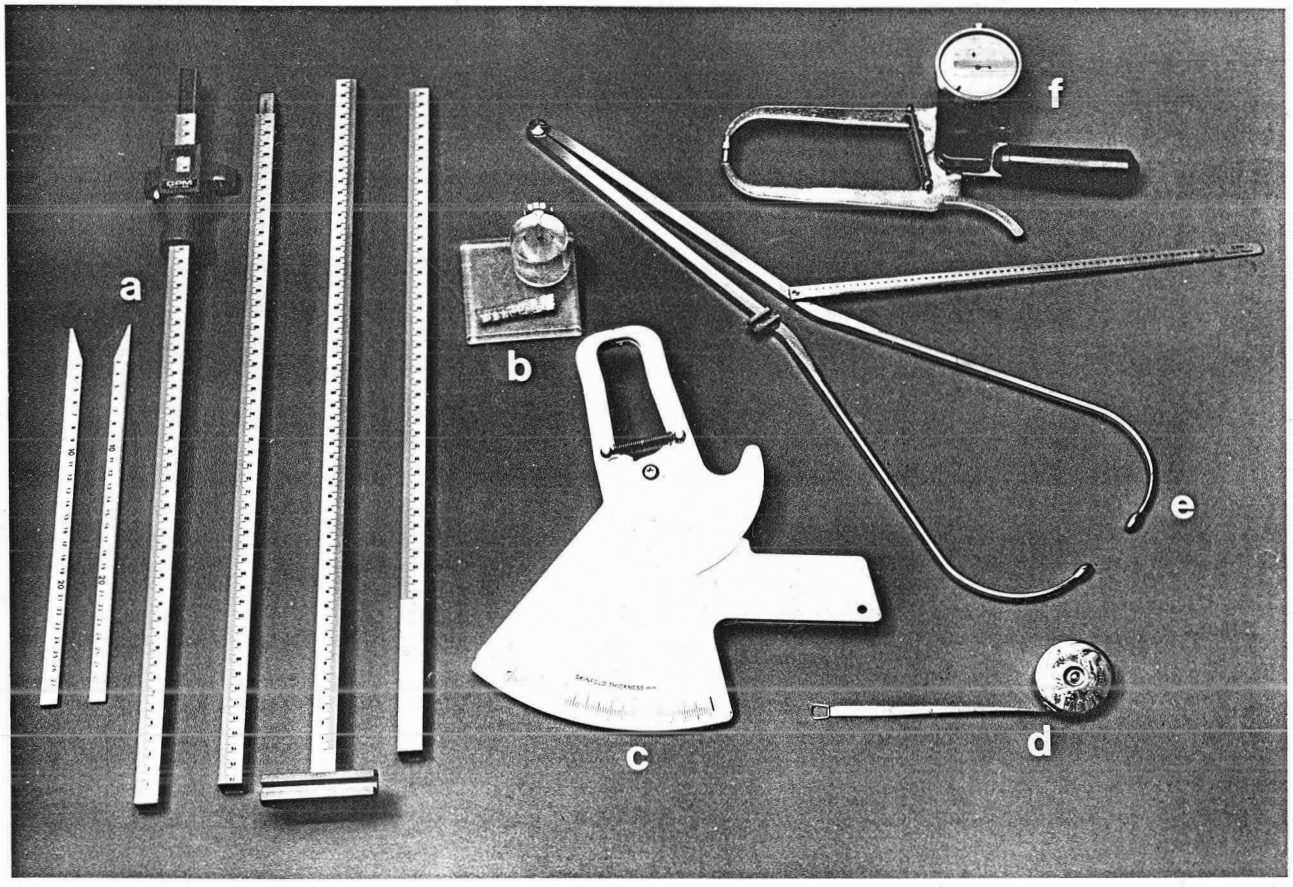
Bone Caliper (not shown)

These instruments are described in Appendix 2.

SKINFOLDS

The first series of measures taken were the skinfolds. These were taken at each of the sites listed below, first using the Harpenden Caliper, and then the Slimguide Caliper. The former measures were used in the subsequent model development.

Figure 2.1 "Anthropometric Instruments."



The sites were:

Subscapular
Triceps
Biceps
Maximum forearm
Mid forearm
Dorsum of the hand
Anterior thigh
Medial thigh
Posterior thigh
Supra-patellar
Medial calf
Dorsum of the foot
Pectoral
Iliac crest
Abdominal

Some difficulty was experienced in taking some trunk and thigh skinfolds. This was partly due to the obesity level of some of the subjects, partly due to the stiffness of the cadavers after so long a period at a low temperature, and, particularly in the thighs, partly due to the flow of embalming fluid into the limbs as a result of being suspended overnight prior to measurement.

GIRTHS

All girths were measured using a Keuffel and Esser Whyteface steel anthropometric tape (No. 860358). Girth measurements were made at each of the following sites:

Axillary arm
Triceps
Minimum arm (Proximal epicondyle humerus)
Elbow
Maximum forearm

Mid forearm
Proximal styloid
Bi-styloid
Distal styloid
Metacarpale
Proximal phalanx of third digit
Upper thigh
Mid thigh
Supra-patellar
Mid-patellar
Infra-patellar
Maximum calf
Mid-calf
Minimum ankle
Bi-malleolare
Highest point of the arch
Metatarsale
Proximal phalanx of the hallux
Forehead
Nasion
Mandible
Suprathyroid
Infrathyroid
Axillary trunk
Mesosternale
Thelion/Breastfold
Xiphion
Waist
Gluteal

DIRECT LENGTHS

Direct lengths were measured with the Siber-Hegner GPM anthropometer of the Martin type assembled in the sliding caliper mode. The direct lengths were:

Acromiale - Radiale
Radiale - Stylion
Stylion - Metacarpale III
Stylion - Dactylion
Trochanterion - Tibiale
Tibiale - Malleolare Laterale
Malleolare Laterale - Ball of Heel
Akropodion - Pternion
*Vertex - Tragion

*Vertex - Mastoid
*Vertex - Menton
*Inion - C7
C7 - Coccyx
Total Suspended Length (Vertex - Ball of Heel)
*Total Supine Length (Vertex - Ball of Heel)

* = Measured in the supine position.

BREADTHS

Limb breadths were measured with the Adapted Mitutoyo bone calipers, as described by Carter (1980). These were:

Bi-epicondylar humerus
Bi-styloid
Metacarpale
Bi-condylar tibia
Bi-malleolare
Submalleolare
Metatarsale

Head breadths were measured with the Sibner-Hegner GPM widespreading caliper. These were:

Bi-tragion breadth
Bi-zygomatic breadth

Trunk breadths were measured with the Siber-Hegner GPM anthropometer of the Martin type assembled in the sliding caliper mode. These were:

Bi-acromial
Mesosternale
Xiphion
Bi-iliocristal
Bi-trochanteric

DEPTHS

Hand and foot depths were measured using the Adapted Mitutoyo bone calipers. They were:

Metacarpale III
Metatarsale III

The head and trunk depths were measured with a Siber-Hegner widespreading caliper. They were:

Inion-glabella
A-P chest (mesosternale)
A-P chest (Xiphion)

The buttock depth was measured using a Siber-Hegner anthropometer in the single mode, with the unarmed base resting on the tray on which the cadaver was supine.

WEIGHT IN AIR

Following completion of all the anthropometric measures, the cadaver was weighed on a Beam Scale prior to the underwater weighing procedure.

HYDROSTATIC WEIGHING

The total body hydrostatic weighing was conducted in a large stainless steel tank 2 metres x 1 metres x 0.75 metres. The apparatus used to perform the measurement is shown in Figure

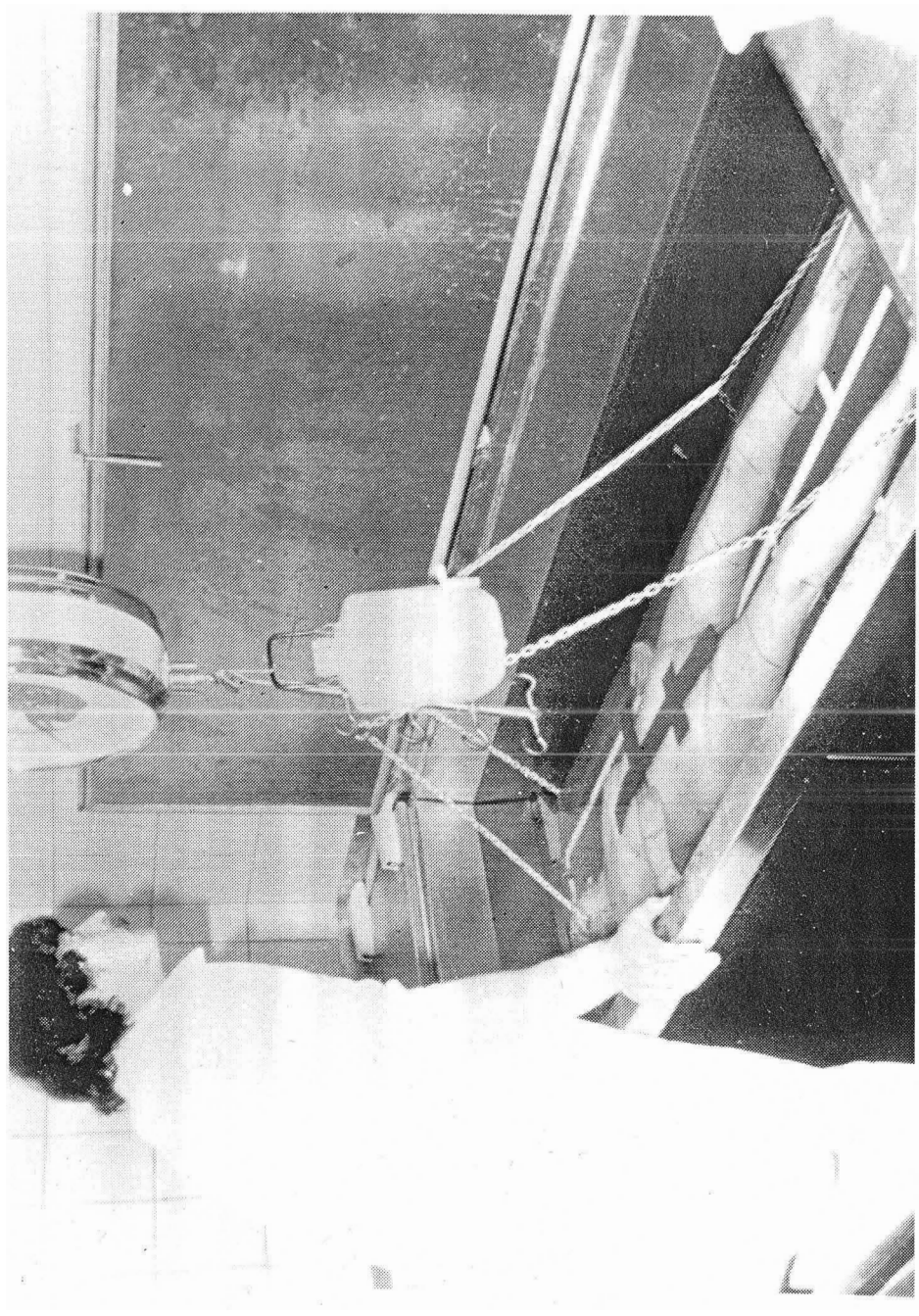
2.2. It consisted of a tubular steel frame, suspended by four chains from a Toledo Scale, and a large steel Greek cross for weighting the cadaver. The scale was zeroed prior to each weighing by attaching a large plastic bottle to it with only the chains suspended from it. The bottle was then filled to the level which elicited a zero reading on the scale. The frame and cross were then attached to the chains and their combined underwater weight measured. The bottle was removed from the scale. The cadaver was placed on the tray, immersed in the tank and weighted down by the cross. The calibration bottle was reattached to the cross-bar of the scale and the hydrostatic weight of cadaver, frame and cross were noted, after a period of time (at least ten minutes) to allow air to escape from within the body and fill the lungs with water. The cadaver was then placed on a large steel tray, dried with a towel and reweighed to establish the weight of water taken into the lungs during the hydrostatic weighing procedure.

SEGMENTATION

The following day the cadaver was segmented and the limb segments dissected.

The segmentation was not carried out in any particular order, save that the entire limb was severed from the trunk prior to division into its three parts viz. arm, forearm and hand, or thigh, leg and foot. The anatomical segmentation

Figure 2.2 "Total Body Hydrostatic Weighing Apparatus"

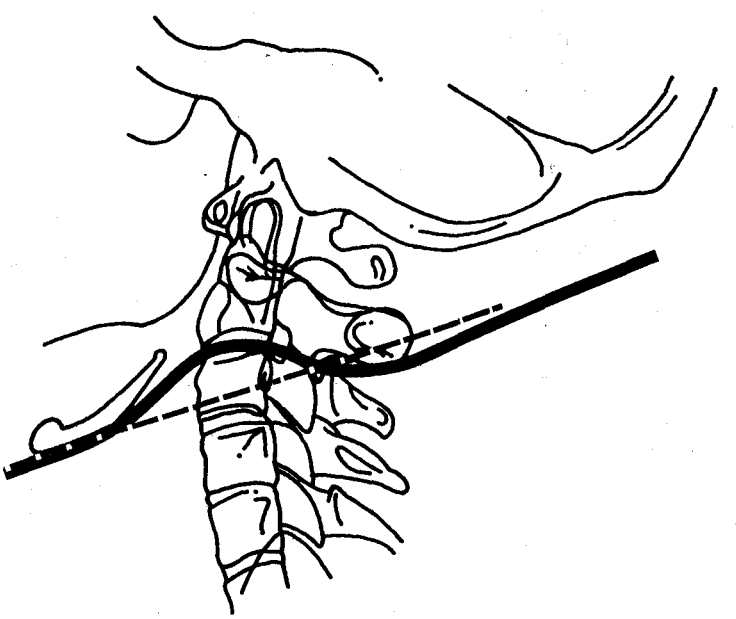


procedures are described in the following pages, with accompanying figures showing the planes of segmentation. The solid black line in each figure (2.3 to 2.9) denotes the anatomical segment plane. For ease of comparison, the biomechanical segmentation plane (as used by Clauser et al., 1969) has been included in each figure. This is denoted by the serrated line.

1) Neck

The cut began at the chin/neck junction inferior to the hyoid bone and continued posteriorly between the 2nd and 3rd vertebral bodies and to completion through the skin on the back of the neck. Every effort was made to maintain the line of the cut as near to the transverse plane as possible. This line was very similar to that of Clauser et al. (1969) and left the majority of the neck assigned to the trunk segment. (See Figure 2.3)

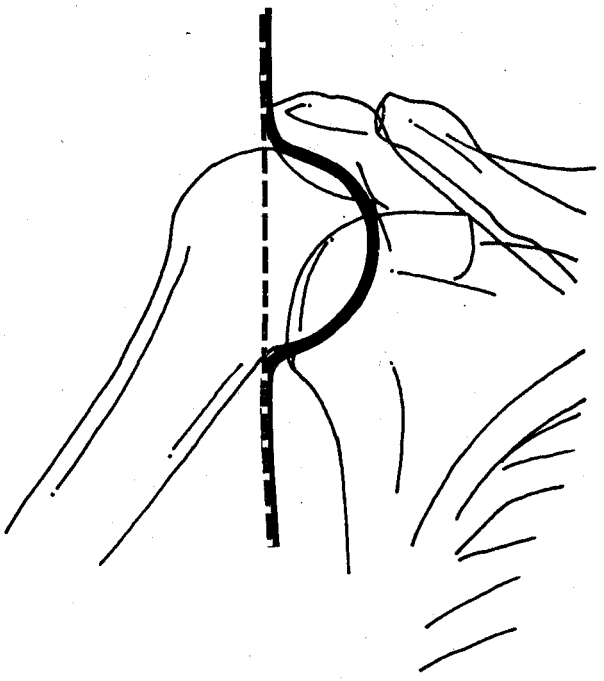
Figure 2.3 "Cutting Plane for Neck Segmentation".



2) Shoulder

The arm was abducted slightly and the cut made in a vertical plane from the axillary fold to the lateral border of the acromion process. The cut circumscribed the limb through the soft tissue from skin to bone. The segmentation was then completed at this site by disarticulation of the head of the humerus from the glenoid fossa. This paralleled Clauser et al.'s(1969) technique in terms of the line of cut, but included no severance of the humeral head as did Clauser's method. (See Figure 2.4)

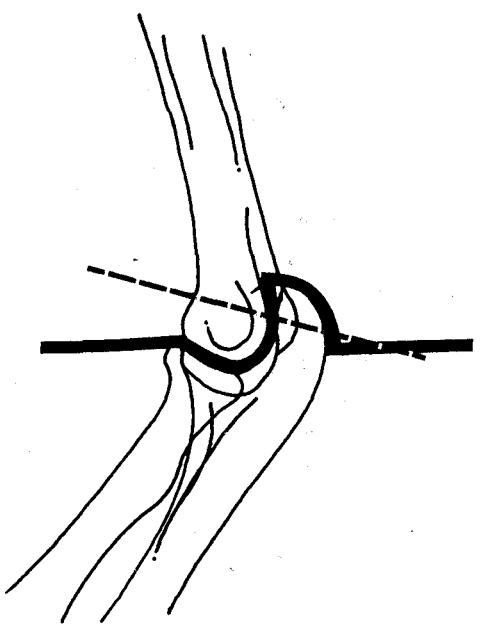
Figure 2.4 "Cutting Plane for Shoulder Segmentation".



3) Elbow

The elbow was severed by a horizontal cut at right angles to the long axis of the arm through the anterior elbow fold, the cavum articulare of the radio-humeral joint, and the posterior elbow, to the bone. The cut was completed by circumvention and disarticulation of the olecranon process. (See Figure 2.5)

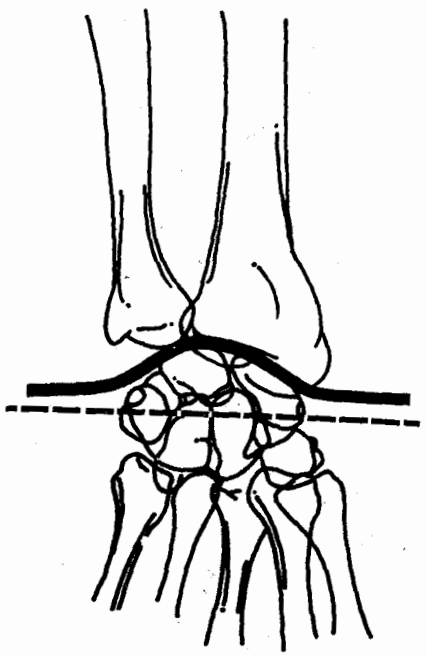
Figure 2.5 "Cutting Plane for Elbow Segmentation".



4) Wrist

The wrist cut was through the cavum articulare of the radio-carpal joint in a slightly elliptical plane at right angles to the long axis of the forearm. (See Figure 2.6)

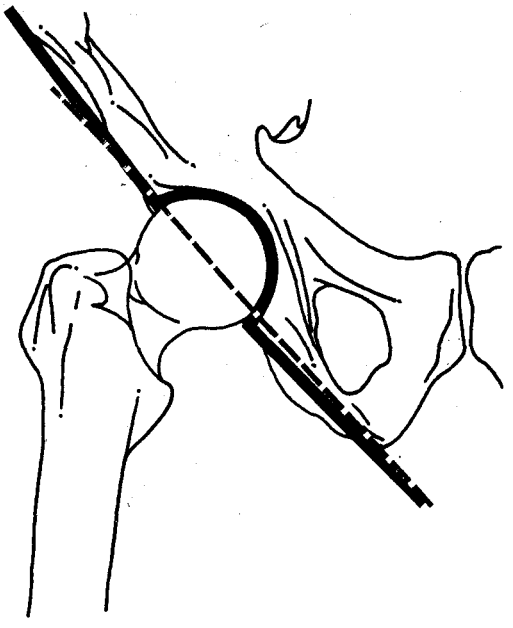
Figure 2.6 "Cutting Plane for Wrist Segmentation".



5) Hip

The cut followed the line of the inguinal ligament from the anterior superior iliac spine to the pubic tubercle, inferiorly round the pubis, along the anal fold of the gluteals, and up to the posterior superior iliac spine. The soft tissue was then excised from the external aspect of the pelvis and the head of the femur disarticulated from the acetabulum. (See Figure 2.7)

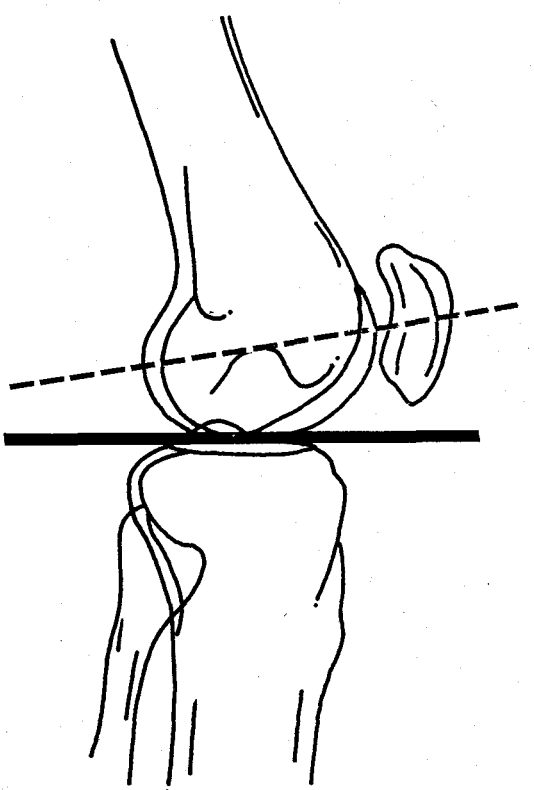
Figure 2.7 "Cutting Plane for Hip Segmentation".



6) Knee

The knee incision was a straight cut through the cavum articulare. This left the patella entirely with the thigh segment. (See Figure 2.8)

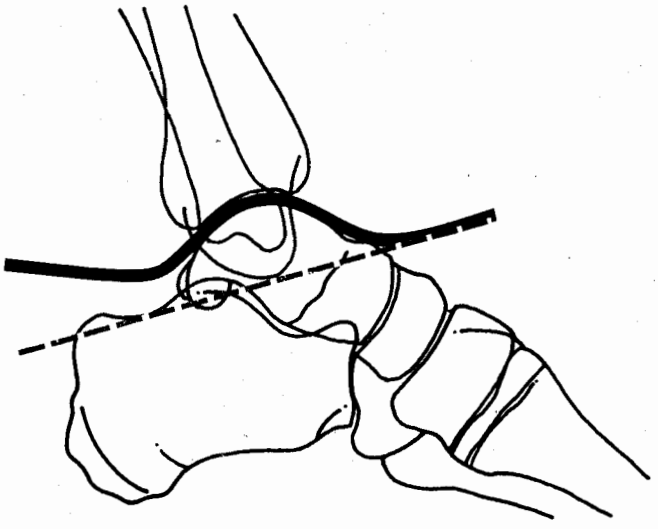
Figure 2.8 "Cutting Plane for Knee Segmentation".



7) Ankle

The cut was a sinuous one beginning immediately distal to the medial malleolus, circumscribing the talus and ending immediately distal to the lateral malleolus. The soft tissue posterior to the ankle joint was severed at the level of the malleolar cut. (See Figure 2.9)

Figure 2.9 "Cutting Plane for Ankle Segmentation".

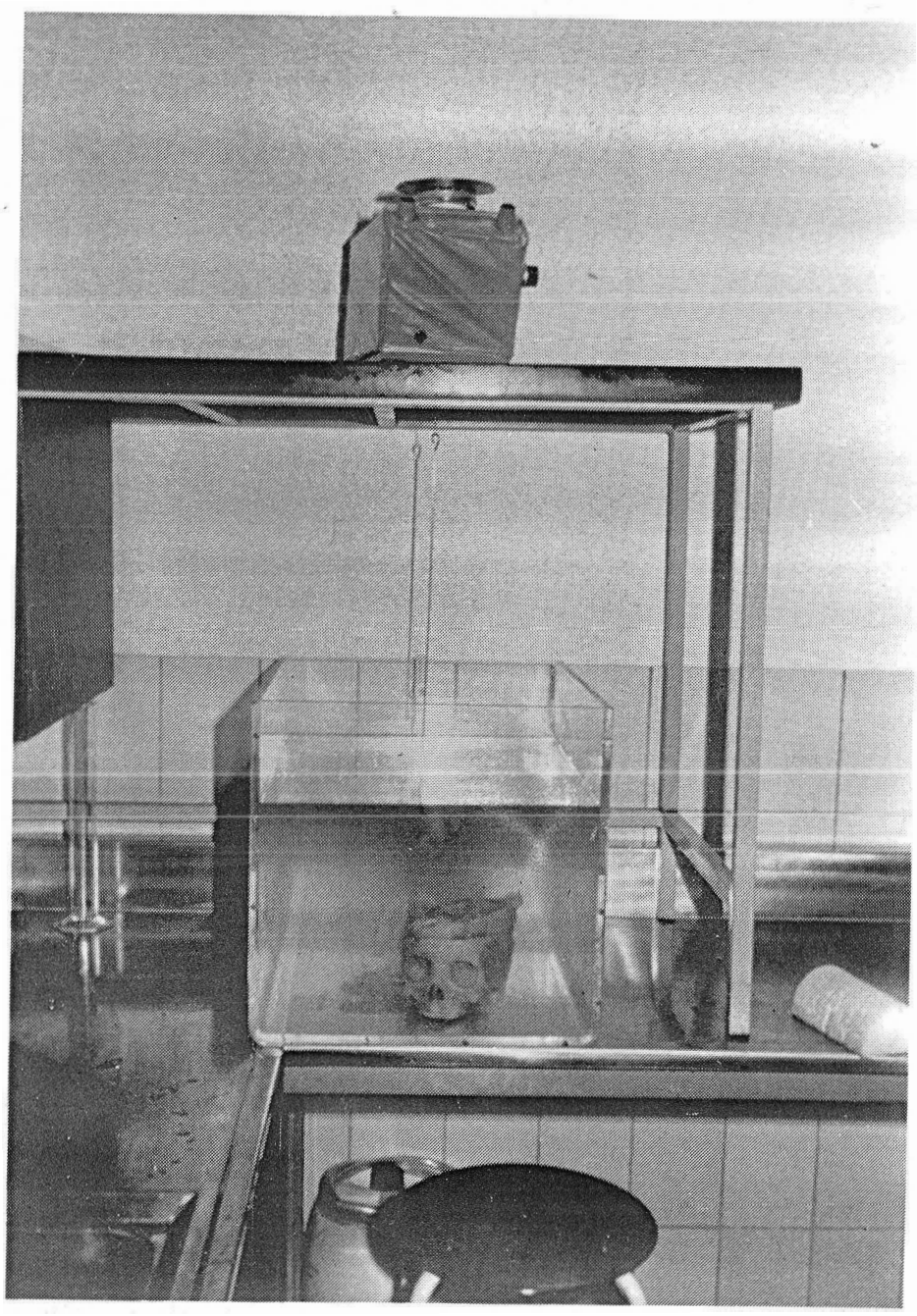


WEIGHING IN AIR AND UNDER WATER

Each of the 14 segments was weighed in air using a Sartorius V digital balance for the smaller segments and a Beam Balance scale for the heavier larger ones. The weighing apparati were calibrated daily with brass and steel calibration weights.

Each segment was also weighed under water. The limb and head segments were weighed to the nearest gram in a glass tank using a Mettler Precision Scale as shown in figure 2.10. The trunk was weighed in the large stainless steel tank, by the Toledo Scale, using the same protocol as utilised to hydrostatically weigh the entire cadaver. Repeat weighings were carried out for each segment. Discrepancies of more than 1 gm. resulted in further measures being taken until agreement within 0.5 grams was achieved between successive weighings.

Figure 2.10 "Segment and Tissue Hydrostatic Weighing Apparatus."



FLUID LOSS

As the segmentation and dissection proceeded, fluid was lost from the tissues by evaporation and by direct leakage.

To minimise evaporation, segments were wrapped in cellophane immediately after segmentation and whenever not actually being dissected. In addition, all tissues that had been fractionated were kept in airtight plastic containers until the tissue for each segment had been collected and was ready for weighing in air and under water. Leaked fluid was collected continually during the course of the day and weighed, both after the segmentation and at the end of the dissection. The weighing was done in a container and the weight of the fluid was obtained by subtraction. The fluid loss for the sample ranged from 1% to 2.5% of the total body weight before dissection.

FRACTIONATION

The weighed segments were distributed amongst the dissection team for fractionation.

For each segment, the skin was removed first and placed in a separate container. Subcutaneous adipose tissue was dissected away from the skin and from the surface of the flayed segment and put in a second container. (The containers used were small plastic buckets with airtight lids. The lids were kept on the buckets at all times when a tissue was not actually being transferred to or from a bucket.)

LEAN BODY ANTHROPOMETRY

Following removal of the skin and subcutaneous adipose tissue, anthropometric measures were made on the limb segments. The measures paralleled those girths and breadths taken when the body was intact. Consequently, their descriptions are the same as those in Appendix 3. The anthropometry performed was as follows:

Arm
- Axilla girth
- Triceps girth
- Minimum arm girth
- Bi-epicondylar girth
- Bi-epicondylar breadth

Forearm
- Maximum forearm girth
- Mid forearm girth
- Proximal wrist girth
- Bi-styloid girth
- Bi-styloid breadth

Hand
- Metacarpal girth
- Proximal Phalanx III breadth
- Metacarpal III depth

Thigh
- Upper thigh girth
- Mid thigh girth
- Suprapatellar girth
- Bi-epicondylar breadth

Leg
- Infra-patellar girth
- Maximum leg girth
- Mid leg girth
- Ankle girth
- Bi-condylar tibia breadth
- Bi-malleolar breadth

Foot
- Arch girth
- Metatarsal girth
- Proximal phalanx hallux girth
- Metatarsal III depth

FRACTIONATION (continued)

The fractionation continued with the further dissection of the segment into its muscular and bony parts. Any adipose tissue located during this stage was allocated to the subcutaneous adipose tissue. The bones were scraped very carefully to remove as much adherent tissue as possible.

WEIGHING OF THE FRACTIONATED SEGMENT COMPONENTS

Once the limb segments had been fractionated into their four components, viz. skin, adipose tissue, muscle and bone, each of the components was weighed, both in air and under water. Weighings in air were made to the nearest 0.1 gm, using a Sartorius V digital balance. Weighings under water, using the same system as used for the total segment weighings (shown in Figure 2.10), were also made to the nearest 0.1 gm, using a Mettler balance.

Since the adipose tissue, in nearly all cases, had a density of less than 1.0 (kg cubed per cubic meter) it was necessary to use a brass weight to prevent the tissue floating. This weight plus the weight of the gauze and wire used to suspend and contain the tissue was subsequently subtracted from the recorded weights.

To simplify adjusting the underwater weighings the brass weight was used in all weighings for each of the four components.

Bones were weighed individually in the forearm (radius and ulna), thigh (femur and patella) and leg (tibia and fibula) segments. The hand and foot bones were weighed collectively for those segments.

OSTEOMETRY

After the completion of fractionation, osteometric measures were taken on the arm, forearm, thigh and leg bones. The measures are defined in Appendix 4.

The reference distances were utilised in this section also, so that the corresponding girths would be measured at the approximate site on the bone at which the whole body and lean body girths were measured. Eleven combination measures were taken on those segments which contained two long bones (five in the forearm and six in the leg). These were:

Forearm
- Maximum forearm girth
- Mid forearm girth
- Minimum wrist girth
- Bi-stylion girth
- Bi-stylion breadth

Leg
- Tibiale-malleolar externus length
- Maximum calf girth
- Mid calf girth
- Minimum ankle girth
- Bi-malleolar girth
- Bi-malleolar breadth

The osteometric measures on individual bones were:

Maximum humerus length
Mid humerus girth
Proximal epicondylar humerus girth
Bi-epicondylar humerus girth
Bi-epicondylar humerus breadth
Ulna length
Maximum forearm ulnar girth
Mid ulnar girth
Radius length
Maximum forearm radial girth
Mid radial girth

Maximum femur length
Trochanterion-condyle length
Upper femur girth
Mid femur girth
Bi-epicondylar femur girth
Bi-epicondylar femur breadth

Maximum tibia length
Tibiale mediale - malleolare internus length
Maximum calf tibial girth
Mid calf tibial girth
Maximum fibula length
Head of fibula - malleolare externus length
Maximum calf fibular girth
Mid calf fibular girth

These measures are defined in Appendix 4.

FLUID ADJUSTMENT

The underwater weights were all first adjusted for the tare weight as mentioned above. Once this had been done, volumes of tissues were calculated on the basis of Archimedes' Principle (outlined by Katch and McCardle,1983) that an object immersed in water experiences an upthrust equal to the weight/volume of water displaced i.e. its weight as measured underwater is less than its weight as measured in air by an amount equal to its volume.

Weights in air and volumes were then adjusted for fluid loss experienced during the course of segmentation and dissection. This adjustment was carried out in four stages.

1. Firstly, each segment weight was adjusted. This was done by summing the observed segment weights and subtracting the sum from the observed totals. The difference was then multiplied by the ratio of each segment weight over the summed total and added to that segment to obtain the fluid-adjusted segment weight.
2. The volume of each segment was then increased by the same absolute amount on the assumption that the increased weight was made up of fluid at a density of 1.0 (kg cubed per cubic meter). Segment densities, when calculated later, were based on the adjusted values.

3. The third adjustment stage consisted of increasing the weights of the four component tissues within each segment, on the same basis as in 1, so that the adjusted tissue weights added up to the adjusted segment weight.
4. Lastly, the volumes were adjusted for each tissue (as in 2).

The overall effect of the adjustments was to restore the situation wherein the sum of all individual tissue amounts corresponded with the observed total body weight immediately prior to dissection. The average adjustment at the segment level was 5% and at the tissue level 9%.

This method of adjustment does not correspond fully with the method used by Clauser et al. (1969), who, although they made the weight adjustment in the same manner, adjusted the volume by an amount necessary to retain the same density. Clauser et al.'s(1969) method, therefore, assumed that the fluid lost was of the same density as the limb segment.

CLAUSER SAMPLE

Clauser et al.'s(1969) methodology is described fully in Aerospace Medical Research Laboratory Report, TR-69-70, "Weight, Volume and Centre of Mass of Segments of the Human Body"(1969). The differences between the dissection phase of Clauser's study and that of the "anatomical" dissection, described above, were in the segmentations at the shoulder, elbow, hip, knee and neck. Clauser's segmentation lines divided the segments at the end of

their biomechanical links.

Clauser's sample consisted of 13 male cadavers selected on the basis of a) Age at death; b) Overall physical appearance, including evidence of pre- or post-mortem wasting; c) Evidence of debilitating diseases or accidents before death, including coroner's statement as to cause of death; d) Body weight; e) Stature.

Statistical Analysis

The statistical analysis of the models developed would be handled in four stages.

1. To examine differences in individual segment prediction between models on the estimating sample, the Repeat Measures Test (Hull and Nie, 1981) would be used. This test would first be applied using a Split Plots option to examine the normality of the distribution. If the distribution was normal, the test would then be repeated using Wilks' Lambda to identify significant differences between the models based on the percentage discrepancy between the predicted and observed masses. If the distribution was not normal, the Friedman Test (Hull and Nie, 1981) would be used to effect the same analysis by a non-parametric approach.
2. To examine differences in individual segment prediction between models on an independent sample, Student's "t" Test (Ferguson, 1976) would be used to compare a selected

pair of models. The test would be One-Tailed with Paired Samples.

3. To examine differences between models in accounting for total bodyweight in in vivo samples, the Repeated Measures Test would be used again, first with Split Plots, then with Wilks' Lambda. If necessary, the Friedman Test would again be used. Normality of distribution would be checked by the Kolmogorov-Smirnov Test (Hull and Nie, 1981).
4. To examine significant differences in prediction between two selected models (those two with the smallest mean percentage discrepancy between predicted and observed bodyweight), the Repeat Measures Test or the Friedman Test would be applied using Special Contrasts to compare the two selected models.

III. DATA FROM THE ANATOMICAL SAMPLE

Chapter Three describes the data obtained from the cadaver dissection. The data is unique in the areas of body composition and segmentation. It is important that it be set out clearly for the benefit of these fields.

The sample was specifically selected to provide as wide a range of morphologies as was possible within the limitations of the research project. To this end both males and females were included. In addition, the presence of Subject I, a thin specimen, and Subject 4, a 16 year old male, ensured a greater heterogeneity within the sample.

Over 450 measured variables and numerous derived variables (e.g. density, percentage weights,) contributed to a large data assembly. The complete set of raw data (with the coded variables defined) is included in Appendix 5. A number of variables have been selected for each segment, which indicate the general segmental status of the individual and show some of the anthropometric values which are thought to reflect the segmental mass. The variables chosen include all those used to construct the various models. Means and standard deviations are also given for each variable. The contents of each table are self explanatory.

	SEX	Age at Demise (decimal years)	Total Weight before Dis-section	Total Volume	Total Density	Total Supine Length
1	Male	69.0	43600.0	42060.0	1.037	169.6
2	Male	78.0	66300.0	64640.0	1.026	161.3
3	Female	79.0	50900.0	50810.0	1.002	148.5
4	Male	16.0	80100.0	78460.0	1.021	178.4
5	Female	79.0	49000.0	49200.0	0.996	149.9
6	Female	79.0	55750.0	54490.0	1.023	162.0
Mean			57608.3	56610.0	1.017	161.6
Standard Deviation			13417.9	13012.8	0.015	11.4

In this , and all subsequent tables in this chapter, weights are in grams; volumes are in millilitres; densities are in kilograms cubed per cubic meter; skinfolds are in millimeters; and lengths, girths and breadths are in centimeters. The skinfold values are those obtained with the Harpenden Skinfold Caliper as these were the ones used in the model development.

	Weight of Head	Volume of Head	Density of Head	Head Girth	Percent of Body Weight
1	3701.1	3367.9	1.099	53.6	8.5
2	4532.3	4160.8	1.089	55.7	6.8
3	3701.1	3410.9	1.080	52.7	7.3
4	5174.6	4716.5	1.097	59.1	6.5
5	3481.8	3215.8	1.083	53.9	7.1
6	4329.5	4041.9	1.070	55.4	7.8
M	4153.4	3819.0	1.087	55.1	7.3
S	644.6	584.1	0.010	2.3	0.7

	Weight of Trunk	Volume of Trunk	Density of Trunk	Trunk Girth Meso-Sternale	Trunk Length Cervicale to Coccyx
1	20234.6	20864.6	0.970	78.6	60.2
2	33465.8	33495.8	0.999	95.3	63.2
3	24262.7	24714.7	0.982	85.7	52.4
4	35336.0	36031.0	0.981	101.3	60.7
5	21218.9	22218.9	0.955	84.2	54.3
6	25083.6	25051.6	1.001	89.1	56.9
M	26600.3	27062.8	0.981	89.0	57.9
S	6335.5	6217.0	0.018	8.2	4.1

	Bi-ilio-cristal Breadth	Waist Girth	Abdominal Skinfold	Percent of Body Weight
1	31.5	63.1	2.5	46.4
2	29.0	88.5	10.0	50.5
3	29.2	78.5	18.3	47.7
4	27.6	84.8	8.0	44.1
5	27.4	75.6	12.8	43.3
6	31.5	73.2	10.4	45.0
M	29.4	77.3	10.3	46.2
S	1.8	9.0	5.2	2.6

	Weight of Left Arm	Volume of Left Arm	Density of Left Arm	Left Triceps Girth	Acromiale Radiale Length	Percent of Body Weight
1	1049.7	1036.3	1.013	18.3	33.8	2.4
2	1650.1	1600.0	1.031	28.8	32.2	2.5
3	1347.3	1332.5	1.011	24.2	30.3	2.6
4	2267.3	2159.4	1.050	30.9	35.1	2.8
5	1508.3	1475.9	1.022	27.0	28.4	3.1
6	1449.4	1409.5	1.028	24.0	34.2	2.6
M	1545.4	1502.3	1.026	25.5	32.3	2.7
S	406.9	373.3	0.014	4.4	2.6	0.2

	Weight L. Arm Skin	Volume L. Arm Skin	Weight L. Arm Fat	Volume L. Arm Fat	Weight L. Arm Muscle	Volume L. Arm Muscle
1	88.7	88.3	55.5	53.2	627.5	599.1
2	134.9	129.1	593.3	621.2	705.2	679.9
3	43.2	42.4	710.4	751.3	439.8	425.5
4	162.0	151.3	791.5	829.9	1041.5	979.1
5	95.2	90.3	758.7	797.6	481.5	455.2
6	92.2	86.9	629.2	658.3	536.8	510.5
M	102.7	98.0	589.8	618.6	638.7	608.2
S	41.1	37.9	272.3	288.3	219.8	204.5

	Weight L. Arm Bone	Volume L. Arm Bone	Left Epicond. Humerus Breadth	Left Triceps Skinfold
1	278.0	226.5	6.92	3.5
2	216.8	180.7	6.62	19.2
3	154.0	128.9	5.11	16.7
4	272.3	211.5	7.46	28.9
5	172.9	143.2	6.30	33.6
6	191.2	156.6	6.71	20.9
M	214.2	174.6	6.50	20.5
S	51.6	38.7	0.80	10.5

	Weight of R. Arm	Volume of R. Arm	Density of R. Arm	Right Triceps Girth	Right Acromiale Radiale Length	Percent of Body Weight
1	1049.7	1036.3	1.013	18.0	34.5	2.4
2	1660.2	1612.3	1.030	27.8	32.1	2.5
3	1582.1	1557.0	1.016	28.6	30.1	3.1
4	2225.7	2106.5	1.057	30.1	35.0	2.6
5	1390.5	1369.2	1.016	26.3	30.1	2.8
6	1544.1	1503.1	1.027	24.3	34.1	2.8
M	1575.4	1530.7	1.026	25.8	32.6	2.7
S	385.1	349.3	0.016	4.3	2.2	0.3

	Weight R. Arm Skin	Volume R. Arm Skin	Weight R. Arm Fat	Volume R. Arm Fat	Weight R. Arm Muscle	Volume R. Arm Muscle
1	88.8	88.3	63.7	60.7	599.1	571.8
2	137.3	130.5	620.8	647.6	670.4	647.9
3	106.6	102.2	754.7	791.2	566.9	549.9
4	147.1	137.5	730.8	763.8	1069.9	1005.1
5	94.6	91.4	679.3	722.2	445.1	424.6
6	96.0	89.9	652.5	686.4	596.7	570.0
M	111.7	106.6	583.6	612.0	658.0	628.2
S	24.5	21.9	259.4	275.0	214.8	198.3

	Weight R. Arm Bone	Weight R. Arm Bone	Right Epicond. Humerus Breadth	Right Triceps Skinfold
1	298.1	248.6	6.87	3.7
2	231.7	196.2	6.63	24.9
3	153.9	128.7	6.46	17.4
4	277.8	212.8	7.63	24.6
5	171.5	143.0	5.71	26.0
6	198.9	163.3	5.91	26.8
M	222.0	182.1	6.54	20.6
S	57.8	45.4	0.70	8.9

	Weight of L. Forearm	Volume of L. Forearm	Density of L. Forearm	Left Maximum Forearm Girth	Radiale Stylion Length	Percent of Body Weight
1	615.7	602.4	1.022	19.1	27.4	1.4
2	829.1	779.8	1.063	23.7	26.2	1.3
3	797.3	784.1	1.017	21.8	22.6	1.6
4	1116.2	1032.3	1.081	27.3	28.6	1.4
5	732.0	688.2	1.064	23.4	22.2	1.5
6	616.4	570.4	1.081	21.2	26.2	1.1
M	784.4	742.9	1.055	22.7	25.5	1.4
S	185.3	166.9	0.028	2.8	2.6	0.2

	Weight Left F/Arm Skin	Volume Left F/Arm Skin	Weight Left F/Arm Fat	Volume Left F/Arm Fat	Weight Left F/Arm Muscle	Volume Left F/Arm Muscle	Weight Left F/Arm Bone	Volume Left F/Arm Bone
1	53.4	52.1	14.6	14.6	375.8	355.5	171.9	129.1
2	56.9	54.1	200.3	208.9	449.3	429.1	122.6	98.4
3	95.8	92.1	369.2	390.1	253.0	243.7	79.4	62.4
4	85.5	78.9	236.0	245.6	649.2	611.8	145.5	104.7
5	67.2	66.0	262.2	270.2	307.8	289.1	94.8	74.7
6	59.1	55.7	135.2	138.0	311.7	295.7	110.3	84.4
M	69.7	66.5	202.9	211.2	391.1	370.8	120.7	92.3
S	17.2	16.0	120.3	127.0	143.2	134.3	33.8	23.7

	Weight of R. F/Arm	Volume of R. F/Arm	Density of R. F/Arm	Right Maximum F/Arm Girth	Radiale Stylion Length	Percent of Body Weight
1	635.9	622.6	1.021	20.7	28.3	1.5
2	893.6	850.1	1.051	23.7	26.2	1.3
3	550.3	525.1	1.048	21.8	22.5	1.1
4	1117.7	1028.5	1.087	26.4	27.0	1.4
5	547.3	515.0	1.063	22.0	22.8	1.1
6	721.2	668.2	1.079	21.6	26.3	1.3
M	744.3	701.6	1.058	22.7	25.5	1.3
S	223.8	201.1	0.024	2.1	2.3	0.2

	Weight Right F/Arm Skin	Volume Right F/Arm Skin	Weight Right F/Arm Fat	Volume Right F/Arm Fat	Weight Right F/Arm Muscle	Volume Right F/Arm Muscle	Weight Right F/Arm Bone	Volume Right F/Arm Bone
1	70.2	68.6	28.0	27.8	360.7	343.3	177.0	70.7
2	67.7	64.8	216.6	224.3	485.2	466.8	124.0	49.5
3	27.5	26.3	186.9	196.7	253.6	244.6	82.3	32.3
4	78.0	72.5	224.1	232.1	666.9	624.8	146.7	52.0
5	31.5	29.5	147.4	157.8	278.4	263.2	90.0	34.7
6	70.4	67.8	152.7	156.3	381.7	363.6	116.4	43.9
M	57.9	54.9	159.3	165.8	404.4	384.4	122.7	47.2
S	22.4	21.1	71.7	74.8	152.6	142.1	35.4	13.9

	Weight of L. Hand	Volume of L. Hand	Density of L. Hand	Left Meta-carpal Girth	Stylion-Dactylion Length	Percent of Body Weight
1	403.7	390.2	1.035	19.0	19.9	0.9
2	342.5	319.0	1.074	18.5	17.6	0.5
3	246.9	231.5	1.067	16.0	15.7	0.5
4	452.8	408.0	1.110	19.4	19.6	0.6
5	300.2	275.5	1.090	16.8	15.8	0.6
6	342.0	314.9	1.086	17.9	17.0	0.6
M	348.0	323.2	1.078	17.9	17.6	0.6
S	73.0	67.0	0.025	1.3	1.8	0.2

	Weight Left Hand Skin	Volume Left Hand Skin	Weight Left Hand Fat	Volume Left Hand Fat	Weight Left Hand Muscle	Volume Left Hand Muscle	Weight Left Hand Bone	Volume Left Hand Bone
1	59.8	58.2	50.0	49.6	157.5	149.0	136.4	110.5
2	52.7	50.9	74.0	75.6	126.2	121.7	89.6	76.3
3	37.2	35.4	70.6	73.1	70.8	67.7	68.4	59.4
4	86.9	79.9	74.4	74.4	179.1	167.9	112.3	90.1
5	67.7	64.4	61.9	62.4	93.3	88.1	77.3	66.6
6	55.4	51.3	106.7	106.3	100.8	95.1	79.0	66.0
M	60.0	56.7	72.9	73.3	121.3	114.9	93.8	78.2
S	16.6	15.0	19.0	21.1	41.1	38.4	25.7	19.1

	Weight Right Hand	Volume Right Hand	Density Right Hand	Right M-carpal Girth	Stylion-Dactylion Length	Percent Body Weight
1	464.3	450.9	1.030	21.2	19.9	1.1
2	353.6	328.7	1.076	18.5	16.7	0.5
3	259.6	241.3	1.076	16.4	17.0	0.5
4	429.6	383.7	1.120	19.0	19.2	0.5
5	241.0	219.8	1.096	16.5	15.7	0.5
6	306.4	277.8	1.103	17.4	17.5	0.6
M	342.4	317.0	1.083	18.2	17.7	0.6
S	90.6	88.6	0.031	1.8	1.6	0.2

	Weight Right Hand Skin	Volume Right Hand Skin	Weight Right Hand Fat	Volume Right Hand Fat	Weight Right Hand Muscle	Volume Right Hand Muscle	Weight Right Hand Bone	Volume Right Hand Bone
1	65.4	67.2	81.2	79.5	170.5	162.7	147.2	123.2
2	45.4	43.5	108.5	109.9	107.7	103.3	92.0	78.0
3	46.8	44.8	82.5	83.7	54.2	51.7	76.1	65.1
4	84.9	77.7	79.4	78.1	144.8	135.2	120.5	96.0
5	51.8	49.4	44.6	45.1	68.8	64.3	75.8	65.2
6	60.0	55.3	93.3	91.6	69.8	65.3	83.3	67.7
M	59.0	56.3	81.6	81.3	102.6	97.1	99.2	82.5
S	14.8	13.6	21.1	21.2	46.9	44.6	28.8	23.1

	Weight of Left Thigh	Volume of Left Thigh	Density of Left Thigh	Left Upper Thigh Girth	Trochant-Tibiale Length	Percent of Body Weight
1	4835.6	4811.4	1.005	31.4	41.6	11.1
2	8200.2	8006.5	1.024	48.8	42.9	12.4
3	6613.4	6629.4	0.998	43.2	38.5	13.0
4	11406.2	11148.1	1.023	56.3	45.7	14.2
5	7260.6	7282.6	0.997	45.7	34.3	14.9
6	8031.2	7935.8	1.012	43.6	44.5	14.4
M	7724.5	7635.6	1.010	44.8	41.2	13.3
S	2175.8	2082.2	0.012	8.2	4.2	1.4

	Weight Left Thigh Skin	Volume Left Thigh Skin	Weight Left Thigh Fat	Volume Left Thigh Fat	Weight Left Thigh Muscle	Volume Left Thigh Muscle
1	414.3	412.4	495.6	494.5	3034.8	2937.1
2	489.9	465.4	2885.5	3016.4	4079.6	3973.6
3	352.6	339.7	3622.1	3807.9	2120.2	2082.7
4	519.2	477.2	4717.5	5002.8	5296.2	5005.6
5	442.9	429.3	4190.1	4439.2	2128.4	2050.8
6	452.6	429.7	3880.4	4053.2	3017.1	2930.9
M	445.3	425.6	3298.5	3469.0	3279.4	3163.4
S	58.4	48.6	1501.9	1600.2	1225.2	1145.5

	Weight Left Thigh Bone	Volume Left Thigh Bone	Left Epicond. Femur Breadth	Left Anterior Thigh Skinfold
1	890.9	724.8	9.68	3.9
2	745.2	617.6	9.57	11.3
3	518.6	447.2	8.86	14.8
4	873.3	694.8	10.69	32.0
5	499.1	414.2	9.65	19.3
6	681.0	549.4	9.50	20.9
M	701.4	574.7	9.70	17.0
S	168.6	127.6	0.60	9.5

	Weight of Right Thigh	Volume of Right Thigh	Density of Right Thigh	Right Upper Thigh Girth	Trochant-Tibiale Length	Percent of Body Weight
1	4898.2	4876.0	1.005	30.6	41.9	11.2
2	8391.6	8198.2	1.024	47.9	42.8	12.7
3	7025.6	7013.3	1.002	46.9	37.3	13.8
4	11728.3	11493.9	1.020	57.8	45.9	14.6
5	7291.0	7303.6	0.998	44.1	33.1	14.9
6	7659.3	7573.5	1.011	45.0	43.6	13.7
M	7832.3	7743.1	1.010	45.4	40.8	13.5
S	2239.4	2156.4	0.010	8.8	4.7	1.4

	Weight Right Thigh Skin	Volume Right Thigh Skin	Weight Right Thigh Fat	Volume Right Thigh Fat	Weight Right Thigh Muscle	Volume Right Thigh Muscle
1	491.0	468.0	582.3	573.6	2911.1	2802.6
2	492.7	468.9	3025.5	3164.3	4113.7	3999.7
3	405.3	387.8	3502.6	3673.5	2562.0	2527.6
4	636.4	595.6	4874.5	5180.5	5368.3	5069.9
5	394.1	372.0	4300.8	4569.5	2100.5	2024.4
6	447.9	422.9	3716.4	3887.4	2847.1	2819.3
M	477.9	452.5	3333.7	3508.1	3317.1	3207.3
S	88.0	80.7	1493.3	1601.5	1206.5	1120.1

	Weight Right Thigh Bone	Volume Right Thigh Bone	Right Epicond. Femur Breadth	Right Anterior Thigh Skinfold
1	913.7	715.3	9.70	4.2
2	759.7	616.6	9.68	8.7
3	555.7	465.8	9.85	11.4
4	849.1	646.8	11.00	23.6
5	495.6	399.9	9.76	17.5
6	647.7	505.6	8.94	20.5
M	703.6	558.3	9.82	14.3
S	165.4	120.3	0.66	7.4

	Weight of Left Leg	Volume of Left Leg	Density of Left Leg	Left Max. Leg Girth	Tibiale-Malleolar Length	Percent of Body Weight
1	1876.3	1862.1	1.008	26.1	39.5	4.3
2	2195.1	2051.9	1.070	30.6	38.2	3.3
3	1555.1	1527.1	1.018	26.8	33.0	3.2
4	3252.3	3053.2	1.065	35.0	42.1	4.1
5	1809.8	1731.6	1.045	30.5	34.2	3.7
6	2224.3	2128.5	1.045	29.8	38.1	4.0
M	2152.2	2059.1	1.042	29.8	37.6	3.7
S	594.5	533.3	0.025	3.2	3.4	0.5

	Weight Left Leg Skin	Volume Left Leg Skin	Weight Left Leg Fat	Volume Left Leg Fat	Weight Left Leg Muscle	Volume Left Leg Muscle
1	136.4	129.8	185.8	188.6	959.2	927.2
2	131.2	124.2	366.6	379.0	1217.4	1175.6
3	80.8	80.4	620.9	655.1	544.3	534.4
4	197.3	179.2	961.1	1009.2	1515.4	1430.7
5	100.6	94.6	672.9	710.6	694.2	664.7
6	131.8	128.4	833.8	860.0	803.8	779.1
M	129.7	122.8	606.9	633.7	955.7	918.6
S	39.6	34.2	288.6	303.8	358.5	334.6

	Weight Left Leg Bone	Volume Left Leg Bone	Left Max. Calf Girth	Left Ankle Girth	Left Tibial Length	Left Medial Calf Skinfold
1	594.8	486.7	26.1	18.6	39.5	3.1
2	479.8	403.5	30.6	19.7	38.2	7.7
3	309.2	270.9	26.8	28.9	33.0	24.0
4	578.7	456.3	35.0	23.2	42.1	22.7
5	342.1	285.5	30.5	18.8	34.2	24.6
6	454.9	380.8	29.8	21.0	38.1	26.2
M	459.9	380.6	29.8	21.7	37.5	18.0
S	117.8	87.9	3.2	3.9	3.4	10.0

	Weight of Right Leg	Volume of Right Leg	Density of Right Leg	Right Max. Leg Girth	Tibiale-Malleolar Length	Percent of Body Weight
1	1655.3	1641.4	1.008	24.2	38.8	3.8
2	2163.9	2019.3	1.072	30.7	38.3	3.3
3	1634.5	1593.9	1.025	29.2	34.1	3.2
4	3439.0	3229.6	1.065	36.7	40.9	4.3
5	1895.9	1817.7	1.043	31.7	36.0	3.9
6	1933.4	1836.3	1.053	30.0	37.6	3.5
M	2120.3	2023.0	1.044	30.4	37.6	3.7
S	675.0	610.3	0.024	4.0	2.4	0.4

	Weight Right Leg Skin	Volume Right Leg Skin	Weight Right Leg Fat	Volume Right Leg Fat	Weight Right Leg Muscle	Volume Right Leg Muscle
1	123.2	116.0	177.3	182.8	764.0	733.9
2	110.0	103.1	349.0	364.7	1211.2	1165.4
3	97.8	97.7	656.2	686.2	541.9	530.1
4	239.9	223.1	1019.2	1069.5	1580.5	1495.5
5	107.6	103.6	784.4	811.7	643.0	614.5
6	92.7	88.1	750.8	784.0	671.5	643.3
M	128.5	121.9	622.8	649.8	902.0	863.8
S	55.6	50.4	308.0	322.8	406.2	381.9

	Weight Right Leg Bone	Volume Right Leg Bone	Right Max. Calf Girth	Right Ankle Girth	Right Tibial Length	Right Medial Calf Skinfold
1	590.8	411.5	24.2	17.1	38.8	2.9
2	493.8	365.7	30.7	19.4	38.3	7.5
3	338.5	266.1	29.2	18.8	34.1	25.6
4	599.3	421.1	36.7	24.2	40.9	22.2
5	360.9	273.9	31.7	19.1	36.0	25.6
6	418.3	293.9	30.0	18.5	37.6	24.4
M	467.0	338.7	30.4	19.5	37.6	18.0
S	112.8	69.7	4.0	2.4	2.4	10.1

	Weight of Left Foot	Volume of Left Foot	Density of Left Foot	Left Meta-tarsal Girth	Akropod.-Pternion Length	Percent of Body Weight
1	1150.6	1136.9	1.012	15.8	25.7	2.6
2	829.1	776.0	1.068	22.7	21.8	1.3
3	633.3	613.6	1.032	20.2	19.4	1.2
4	1037.4	951.4	1.090	21.0	27.4	1.3
5	665.2	632.8	1.051	19.6	21.0	1.4
6	779.4	739.1	1.055	21.7	22.8	1.4
M	849.2	808.3	1.051	20.2	23.0	1.5
S	205.9	201.5	0.027	2.4	3.0	0.5

	Weight Left Foot Skin	Volume Left Foot Skin	Weight Left Foot Fat	Volume Left Foot Fat	Weight Left Foot Muscle	Volume Left Foot Muscle	Weight Left Foot Bone	Volume Left Foot Bone
1	141.7	135.2	280.7	278.7	337.4	325.8	390.8	334.9
2	100.2	94.4	237.7	240.2	236.7	226.6	254.6	220.2
3	68.9	65.2	276.6	284.0	106.1	103.5	181.6	167.3
4	181.7	172.6	187.9	188.2	324.7	311.0	343.2	284.2
5	100.1	94.8	219.1	220.0	154.5	149.5	191.5	174.2
6	98.3	92.6	297.6	299.2	159.9	154.9	223.6	196.9
M	115.1	109.1	249.9	251.7	219.9	211.9	264.2	229.6
S	40.0	38.3	42.1	42.9	95.8	91.5	85.0	66.6

	Weight of Right Foot	Volume of Right Foot	Density of Right Foot	Right Meta-tarsal Girth	Akropod.-Pternion Length	Percent of Body Weight
1	1029.5	1015.9	1.013	15.4	25.7	2.4
2	792.8	740.7	1.070	22.3	21.6	1.2
3	690.7	668.5	1.033	20.8	20.8	1.4
4	1117.0	1033.2	1.081	21.3	27.0	1.4
5	657.7	628.9	1.046	19.9	20.3	1.3
6	730.0	687.7	1.062	22.1	22.2	1.3
M	836.3	795.8	1.050	20.3	22.9	1.5
S	191.0	180.8	0.025	2.6	2.8	0.4

	Weight Right Foot Skin	Volume Right Foot Skin	Weight Right Foot Fat	Volume Right Foot Fat	Weight Right Foot Muscle	Volume Right Foot Muscle	Weight Right Foot Bone	Volume Right Foot Bone
1	124.7	117.9	235.5	234.2	280.6	271.2	388.7	327.4
2	93.6	88.7	282.4	282.0	162.0	156.8	254.8	218.9
3	75.8	72.4	251.2	258.6	170.9	167.8	192.8	178.0
4	173.3	162.8	256.3	256.5	329.0	313.6	358.4	297.2
5	86.9	81.5	252.4	256.0	126.1	121.8	192.3	178.5
6	109.9	102.6	215.5	219.5	188.1	180.8	216.5	189.2
M	110.7	104.3	248.9	251.1	209.5	202.0	267.2	231.5
S	35.2	32.8	22.3	21.7	78.1	73.9	85.9	65.0

IV. MODEL DEVELOPMENT

The purpose of this chapter is to describe the procedures involved in developing the various models for the prediction of a) anatomical segment mass, b) anatomical segment tissue masses, c) biomechanical segment masses.

ANATOMICAL SEGMENTAL PREDICTION

REGRESSION MODEL

The cadaver data were used initially to develop a regression model(MCREG) for the prediction of segment masses. The anthropometric variables for each segment were regressed against observed segment weight using a multiple regression analysis (Nie, Hull, Jenkins, Steinbrenner and Bent, 1975), on the Michigan Terminal System at Simon Fraser University.

Initially, regressions were performed for left and right sides separately. The result of this, however, was that the relationships for the right side segments were slightly different from those for the left side segments. Whereas it is not unusual to find contralateral size differences, particularly in athletes, (Takahashi and Uetake,1982), there is no reason to suspect that the relationship between anthropometry and

composition should be different contralaterally. In this study it was considered to be due to the embalming procedure since the fluid was pumped into the body unilaterally under pressure and a completely even distribution was the exception rather than the rule for the cadavers dissected. A number of approaches were tried in order to identify the influence of any bilateral differences.

1. The regression equations were applied to the cadaver sample based on different equations for the left and right side limb segments.
2. Right side equations were used for both sides using left and right side values.
3. Left side equations were used for both sides using left and right side values.
4. Right side equations and right side values were used and duplicated for the left side segments.
5. Left side equations and left side values were used and duplicated for the right side segments
6. Mean values of anthropometry and segment weight for each segment were calculated and a mean regression was developed which applied to segments of both sides.

Analysis of the results by the Repeated Measures Test(Hull and Nie,1981) revealed no significant differences in the prediction of segment mass by any of the above methods. Apparently, cotralateral embalming differences did not affect the relationship between anthropometry and segmental mass.

Therefore, it was decided to adopt the last procedure, (taking the mean values from both sides) - a conceptually more acceptable rationale, than that different sides should demonstrate different relationships *in vivo*, albeit only slightly different. This decision was reinforced by its being the same as that taken by Clauser et al.(1969) in the handling of their data.

Three passes were used for the mean value regression. PIN [1] was set at 0.01 to ensure a conservative level of significance of the variables entering the equation for all three passes.

In the first pass, only intrasegmental anthropometric variables were available for selection.

In the second pass, total body weight was added to the list of predictor variables available for possible selection. This was to enable the selection and use of total body weight if this variable should prove a better predictor than the intrasegmental ones alone.

The third pass consisted of only those intrasegmental predictors which were incorporated in the PROFORMA (See Appendix 6.) used for many years now by the Kinanthropometric Research Unit at Simon Fraser University, and described by Ross and Marfell-Jones(1982).

The rationale of restricting the variable list, in the third run, to those variables on the PROFORMA was based on a)

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[1] PIN (*probability* to go *in* to the equation) controls the entry of a variable in that a variable is only entered if the probability of its F value is smaller than the PIN value.

minimising the overall number of variables needed to be measured in the future, and b) permitting the application of the model to existing large data bases assembled over a number of years, in particular the various Olympic Games data assemblies (Carter, 1982a; Carter, Ross, Aubry, Hebbelinck and Borms, 1982b; de Garay, Levine and Carter, 1977; Ross, Leahy, Drinkwater and Swenson, 1981.)

The regressions which displayed the highest correlation coefficient values overall were selected for use in predicting the standard segment mass values for the Phantom Model. They were chosen on the basis of containing no more than two variables (due to the sample size), with residual degrees of freedom as high as possible (without unduly sacrificing r-squared), r-squared greater than or equal to 0.85, a minimum standard error and a significant f-ratio of less than 0.01.

The predictors in these regression equations, their correlation coefficients, the mean segment masses and their standard errors are reported in Table 4.1.

Table 4.1 "Best Predictors of Segment Masses, in the MiniCAS sample." (any MCAS variables, n=6.)

SEGMENT	VARIABLE	R-SQUARED	MEAN (gms)	STANDARD ERROR (gms)	SIG. OF F-RATIO
HEAD	Body Weight	0.90	4153	225	0.004
TRUNK	Mesosternale Girth	0.94	26600	1774	0.002
ARM	Arm Girth, Arm Length	0.97	1560	88	0.005
F-ARM	Forearm Girth, Forearm Length	0.97	764	42	0.005
HAND	Metacarpal Breadth	0.98	345	13	0.000
THIGH	Body Weight	0.91	7778	733	0.003
CALF	Calf Girth, Tibial Length	0.97	2136	145	0.006
FOOT	Foot Length	0.93	842	58	0.002

The regression equations used to derive the Phantom segment masses and standard deviations were as follows:

HEAD 0.04564*Body Weight(gm) + 1524.2

TRUNK 751.48429*Mesosternale Girth(cm) - 40306.9

ARM 0.02791*Body Weight - 47.6

FOREARM 0.01397*Body Weight - 40.2

HAND 45.97778*Hand Length(cm) - 465.5

THIGH 0.15678*Body Weight - 1253.5

LEG 0.04326*Body Weight - 356.1

FOOT 65.8828*Foot Length(cm) - 670.9

The best regressions from the last run, i.e. including only segmental PROFORMA variables, were selected for inclusion in the regression model for application to other samples. The corresponding information (to that in Table 4.1) for these predictors is shown in Table 4.2.

Table 4.2 "Best Segmental Predictors of Segment Masses." (PROFORMA variables only, n=6.)

SEGMENT	VARIABLE	R-SQUARED	MEAN (gms)	STANDARD ERROR (gms)	SIG. OF F-RATIO
HEAD	Head Girth	0.89	4153	234	0.004
TRUNK	Mesosternale Girth	0.94	26600	1774	0.002
ARM	Arm Girth, Arm Length	0.97	1560	88	0.005
F-ARM	Forearm Girth, Forearm Length	0.97	764	42	0.005
HAND	Hand length,	0.93	345	24	0.009
THIGH	Thigh Girth	0.91	7778	754	0.003
LEG	Calf Girth, Tibial Length	0.97	2136	145	0.006
FOOT	Foot Length	0.93	842	58	0.002

The regression equations for use in a regression model(MCREG) to predict segmental masses in adults were:

HEAD	267.81411*Head Girth - 10594.2
TRUNK	751.48429*Mesosternale Girth - 40306.9
ARM	87.72674*Arm Girth 74.67424*Arm Length - 3119.8
FOREARM	70.7058*Forearm Girth + 25.19786*Forearm Length - 1485.6
HAND	45.97778*Hand Length - 465.5
THIGH	249.69457*Thigh Girth - 3484.9
LEG	114.97555*Calf Girth + 113.77197*Tibial Length - 5599.5
FOOT	65.8828*Foot Length - 670.9

All girths and lengths are in centimeters.

CALCULATION OF ANATOMICAL PHANTOM SEGMENT MASS VALUES

It was important in the construction of the proportionality/deviation model that the Phantom mass ascribed to each segment actually corresponded to the Phantom variables for that segment. Since segment mass values were not, and probably never will be, available from a large sample, these values were, of necessity, obtained from a relatively small sample (n=6).

The only samples on which segmental data were previously available were sex-specific. The use of such samples to build a universal model introduces a bias unless a compensation is made which renders the data unisex. A unique feature of this investigation is the inclusion of three female cadavers in the sample and the inclusion of a young subject.

The predictor variables from Table 4.1 and their concomitant regression equations were utilised to define the Phantom segment masses and their standard deviations for use in the development of the Proportionality/Deviation (P/D) model.

The Phantom p values (Ross and Wilson,1974) were applied to the regression to establish Phantom segment weights. The Phantom (p + s) values (i.e. one standard deviation above the p value) were then applied to the regression model and the segment weights were re-predicted. The difference between the two predictions constituted the Phantom s value for each segment

weight.

For example, substituting the Phantom p-value for bodyweight, in the regression (Table 4.2) for predicting head weight, gives a Phantom p-value for the head segment of 4671.7 gms.

Substituting one Phantom standard deviation above bodyweight into the same equation gives a Phantom segment mass value for the head of 5064.21 gms.

The difference between these two values is, by definition of the hypothesis this model is built on, the Phantom standard deviation for the head segment, i.e. 392.51 gms.

The resultant values established for each segment are shown in Table 4.3.

Table 4.3 Phantom p and s values for Segmental Masses(in gms). (for anatomical segmentation)

Segment	p	s
HEAD	4671.7	392.51
TRUNK	25538.5	3892.69
ARM	1754.9	213.36
FOREARM	1012.0	120.14
HAND	410.2	59.03
THIGH	9471.3	980.59
LEG	2637.7	318.89
FOOT	1059.1	76.42

PROPORTIONALITY/DEVIATION MODEL

The Proportionality/Deviation(P/D) model is based on the Phantom proportionality stratagem of Ross and Wilson(1974) and the fractionation tactic of Drinkwater and Ross(1980).

Using the Phantom stratagem it is possible to express anthropometric measurements as deviations from the equivalent Phantom values. Such deviations are expressed as Phantom z-values, and are calculated using the following formula:

$$z = \frac{1}{s} \left(v * \left(\frac{170.18}{h} \right)^{d} - p \right)$$

where: z is a proportionality score or z-value.
s is the Phantom standard deviation for the given variable.
v is any variable.
170.18 is the Phantom height constant.
h is the subject's height.
d is a dimensional exponent which is 1 for all heights, lengths, breadths, girths and skinfold thicknesses; 2 for all area values; and 3 for all masses and volumes.
p is the Phantom value for the variable.

A significant feature of this strategem is the adjustment for height which scales all values to the Phantom height of 170.18 cm. This permits individual comparison of size-adjusted values as opposed to absolute values and highlights proportionality differences.

The tactic of Drinkwater and Ross(1980) uses groups of selected variables to predict bone, muscle, adipose tissue and residual masses on the basis that the mean deviation of such variables (i.e. the mean z-value within each group) represents a similar deviation in the amount of the four components in the body from the Phantom mass for each component.

Phantom z-values are utilized in this tactic also, to predict the appropriate segment mass by the following formula:

$$M = \frac{Z * S + P}{\left(\frac{170.18}{h}\right)^{d}}$$

where:

M is the estimated segmental mass.
Z is the mean Phantom z-value for the selected subset of variables.
S is the Phantom standard deviation for the segmental mass.
P is the Phantom value for the component mass.
170.18 is the Phantom height constant.
h is the subject's height.
d is a dimensional exponent, which has the value 3 in this application.

The segmentation model also uses groups of selected anthropometric variables, but these were chosen on the basis that a change in their value would reflect a change, not in an overall component such as bone, but in the mass of a particular body segment. The Phantom p and s values for anthropometric variables used in the model are given in Appendix 7.

Once the phantom segment mass parameters had been defined, it was possible to proceed with the development of the P/D

model.

Two aspects had to be considered in developing this model. Firstly, the selection of the best predicting variables within each segment and, secondly, the relative weighting of those variables once they had been converted to Phantom z-values, i.e. deviations from the Phantom mean values for that particular variable.

The variable selection criterion stipulated the inclusion of at least a length, a girth, a bone width and a skinfold for each segment. It was felt that the length and girth would reflect the general size of the segment, the bone width would reflect the amount of bone in the segment and the skinfold would give an indication of the amount of adipose tissue and muscle (when considered in conjunction with the girth). The selection was limited in the case of the head, forearm, hand and foot segments, since not all of the four types of measurement had been utilised in the PROFORMA. Body weight was excluded as a possible predictor since it would be used later as an indirect prediction validation.

The variables selected for each segment are shown in Table 4.4.

Table 4.4 "Predictor Variables for each Segment for the Proportionality/Deviation Model."

Segment	Predictor Variables
HEAD	Forehead girth.
TRUNK	Mesosternal girth, Trunk length, Biiliocristal breadth, Waist girth, Abdominal skinfold.
ARM	Relaxed arm girth, Acromiale-Radiale length, Epicondylar humerus breadth, Triceps skinfold.
FOREARM	Forearm girth, Radiale-Stylion length, Wrist girth.
HAND	Stylion-Dactylion length.
THIGH	Thigh girth, Trochanterion-Tibiale length, Epicondylar femur breadth, Ant.Thigh skinfold.
LEG	Max.Calf girth, Tibiale height, Ankle girth, Med.Calf skinfold.
FOOT	Foot length.

The second aspect, that of the appropriate weighting of the z-values of the predictor variables, was catered for by forcing the desired variables into the regression against segment weight and noting the beta values produced for those variables. The beta values were then utilised to weight the variables. The essence of the model is the calculation of a mean z-value for each segment which will reflect the deviation of that segment mass from the corresponding Phantom value. This was achieved by dividing the sum of the weighted z-values of the predicting variables by the numerical total of the weightings, as described

in Chapter 1,

e.g. MZTRUNK = (ZCHG*7 + ZTRL + ZBIIL + ZWAG - ZABSF)/9.

where: MZTRUNK is the mean Phantom z-value for the trunk.
ZCHG is the Mesosternale Girth expressed in Phantom Mesosternale Girth standard deviations.
ZTRL is the Trunk Length expressed in Phantom Trunk Length standard deviations.
ZBIIL is Biiliocristal Breadth expressed in Phantom Biiliocristal Breadth standard deviations.
ZWAG is the Waist Girth expressed in Phantom Waist Girth standard deviations.
ZABSF is the Abdominal Skinfold expressed in Phantom Abdominal Skinfold standard deviations.
"9" is the arithmetical divisor which ensures that identical Phantom z-values for each of the predicting parameters would give an identical mean z-value for the segment.

The model was applied to various samples using divisors calculated in this manner.

Once the mean z-value for each segment had been calculated, the weight of the segment was predicted using the Drinkwater Tactic formula, described above. For <u>in vivo</u> samples, the model then summed the predicted segment weights to give a predicted

total body weight, and compared this to the observed body weight. The final form of the Anatomical P/D model is shown in Table 4.5. Note that the weights are expressed in kilograms, therefore it is necessary to convert to that unit. The coded variables are as defined in Appendix 5, except that, since mean anthropometry was used to construct the model, final "L" or "R" initials have been omitted.

Table 4.5 "Proportionality/Deviation Model for the Prediction of Anatomical Segment Weight"

```
RHT = 170.18/LTOTSUS

ZHDG = (((HGFHD*RHT)-56)/1.44)
ZHDL = (((HLVERMEN*RHT)-27.27)/1.02)
MZHEAD = (((ZHDG*7)+ZHDL)/10)
PRHEAD = (((392.51*MZHEAD)+4671.7)/(RHT**3))

ZSSSF = (((SFHSUB*RHT)-17.2)/5.07)
ZILSF = (((TSFHIC*RHT)-15.4)/4.47)
ZTRCH = (((TBMESOST*RHT)-27.92)/1.74)
ZABSF = (((TSFHSS*RHT)-15.4)/4.47)
ZWAG = (((TGWAI*RHT)-71.91)/4.45)
ZCHG = (((TGMESOST*RHT)-87.86)/5.18)
ZBIIL = (((TBBIILC*RHT)-28.84)/1.75)
ZTRL = (((TLC7CO*RHT)-59.97)/3.7)
ZBIAC = (((TBBIAC*RHT)-38.04)/1.92)
ZAPCH = (((DAPCHMES*RHT)-17.50)/1.38)
MZTR = ((ZCHG*7+ZBIIL+ZTRL+ZWAG-ZABSF)/9)
PRTRUNK = (((3892.69*MZTR)+25538.51)/(RHT**3))

ZAGR = (((GTR*RHT)-26.89)/2.33)
ZUA = (((LACRAD*RHT)-32.53)/1.77)
ZHUM = (((BEPIHU*RHT)-6.48)/0.35)
ZTPSF = (((SFHTR*RHT)-15.4)/4.47)
MZARM = ((ZAGR*7+ZUA+ZHUM-ZTPSF)/8)
PRARM = (((213.36*MZARM)+1754.9)/(RHT**3))

ZWRG = (((GDISTY*RHT)-16.38)/0.72)
ZFA = (((LRADSTY*RHT)-27.77)/1.37)
ZFAG = (((GMXF*RHT)-25.13)/1.41)
MZFARM = ((ZFAG*8+ZFA+ZWRG)/10)
PRFARM = (((120.14*MZFARM)+1012.0)/(RHT**3))
```

```
ZHA = (((LSTYDAC*RHT)-18.85)/0.85)
PRHAND = (((59.03*ZHA)+410.2)/(RHT**3))


ZTHG = (((GUPTH*RHT)-55.82)/4.23)
ZTHSF = (((SFHANTT*RHT)-27.0)/8.33)
ZTHIGH = (((LTROTIB*RHT)-35.44)/2.12)
ZFEM = (((BEPIFE*RHT)-9.52)/0.48)
MZTHIGH = ((ZTHG*7+ZTHIGH+ZFEM-ZTHSF)/8)
PRTHIGH = (((980.59*MZTHIGH)+9471.3)/(RHT**3))


ZMCSF = (((SFHMEDC*RHT)-16.0)/4.67)
ZANG = (((GMNANK*RHT)-21.71)/1.33)
ZTIHT = (((LTIBMAL*RHT)-37.72)/2.15)
ZCAG = (((GMXCA*RHT)-35.25)/2.30)
MZLEG = ((ZCAG*8+ZTIHT*4+ZANG-ZMCSF)/12)
PRLEG = (((318.89*MZLEG)+2637.7)/(RHT**3))


ZFOOTLN = (((LAKPTE*RHT)-25.50)/1.16)
PRFOOT = (((76.42*ZFOOTLN)+1059.1)/(RHT**3))
```

Where: Weights are in kg.
Skinfolds are in mm.
All other measures are in cm.

Variables prefixed with Z indicate the variable expressed in Phantom standard deviations.
Variables prefixed with M indicate a mean value.
Variables prefixed with PR indicate a predicted weight.

VOLUME-BASED MODELS

To examine the volume approach, the volume of each segment was regressed against the segment mass for each subject in the sample. A correlation of 0.97 or better was found in every segment. Based on the strength of this correlation, and subsequent to discussion with a mathematical statistician, (Arya, 1982), two volume-predicting models were developed.

The first involved the regression of a squared girth times a length against mass for each segment. (This model will contain the initial "X" after the initials "VOL" in its title, e.g. MCVOLXBB.) This gave the correct dimension to the prediction, but limited the model to one predictor (albeit consisting of two variables).

The second used the same two variables, but regressed them separately in the form of the squared girth and the length. (This model will contain the initial "A" after the initials "VOL" in its title, e.g. MCVOLABB.) Although this second volume-based model did not exhibit the dimensional elegance of the first one, it was felt that it might explain more of the variance given the presence of the second separate variable, and should therefore be investigated.

The correlation coefficients, mean segment masses, standard errors and F-ratio significance values for each segment prediction for the MCVOLX model are depicted in Table 4.6. (The

variables are those in the equations in Table 4.7)

Table 4.6 "Statistical Details of MCVOLX Model." (Sample=MiniCAS, n=6)

SEGMENT	R-SQUARED	MEAN (gms)	STANDARD ERROR (gms)	SIG. OF F-RATIO
HEAD	0.77	4153	344	0.02
TRUNK	0.96	26600	1399	0.001
ARM	0.95	1560	94	0.001
F-ARM	0.97	764	35	0.000
HAND	0.93	345	24	0.002
THIGH	0.97	7778	397	0.001
LEG	0.94	2136	172	0.001
FOOT	0.94	842	62	0.010

The equations used for the MCVOLX model are given in Table 4.7. The variables are defined in Appendix 5.

Table 4.7 "Calculation of Anatomical Segment Mass from the Girth Squared TIMES the Length"

```
HEAD=(0.05583*HEAD3)+747.0
        Where: HEAD3=HGFHD2*HLVERMEN
        and    HGFHD2=HGFHD**2

TRUNK=(0.05743*TRUNK3)-107.4
        Where: TRUNK3=TGMESO2*TLC7CO
        and    TGMESO2=TGMESOST**2

ARM=(0.05419*ARM3)+374.0
        Where: ARM3=GTR2*LACRAD
        and    GTR2=GTR**2

F/ARM=(0.05324*FARM3)+53.4
        Where: FARM3=GMXF2*LRADSTY
        and    GMXF2=GMXF**2

HAND=(0.08370*HAND3)+14.2
        Where: HAND3=GDISTY2*LSTYDAC
        and    GDISTY2=GDISTY**2

THIGH=(0.05946*THIGH3)+2618.7
        Where: THIGH3=GUPTH2*LTROTIB
        and    GUPTH2=GUPTH**2

LEG=(0.05984*LEG3)+60.4
        Where: LEG3=GMXCA2*LTIBMAL
        and    GMXCA2=GMXCA**2

*FOOT=(66.31667*LAKPTE)-(0.17967*GMNANK2)-603.6
        Where: GMNANK2=GMNANK**2

        All measures are in cms.
        Segment masses are predicted in gms.
```

* Since there was no correlation between "the squared girth TIMES a length" and the mass for the feet, "the squared girth AND a length" was used for these segments.

The correlation coefficients, mean segment masses, standard errors and F-ratio significance values for each segment prediction for the MCVOLA model are shown in Table 4.8. (The variables are those in the equations in Table 4.9)

Table 4.8 "Statistical Details of MCVOLA Model." (Sample=MiniCAS, n=6)

SEGMENT	R-SQUARED	MEAN (gms)	STANDARD ERROR (gms)	SIG. OF F-RATIO
HEAD	0.89	4153	272	0.03
TRUNK	0.97	26600	1497	0.006
ARM	0.98	1560	76	0.003
F-ARM	0.97	764	41	0.004
HAND	0.97	345	18	0.005
THIGH	0.98	7778	431	0.003
LEG	0.98	2136	126	0.003
FOOT	0.94	842	62	0.014

The equations used for the MCVOLA model are given in Tables 4.9. The variables are defined in Appendix 5.

Table 4.9 "Calculation of Anatomical Segment Mass from the Girth Squared AND the Length"

```
HEAD=(2.35061*HGFHD2)+
     (7.38583*HLVERMEN)-3132.3
      Where: HGFHD2=HGFHD**2
TRUNK=(3.79018*TGMESO2)+
      (278.15858*TLC7CO)-19774.0
      Where: TGMESO2=TGMESOST**2
ARM=(1.81407*GTR2)+
    (66.51366*LACRAD)-1825.6
      Where: GTR2=GTR**2
FARM=(1.51310*GMXF2)+
     (22.64907*LRADSTY)-602.3
      Where: GMXF2=GMXF**2
HAND=(32.06152*LSTYDAC)+
     (0.87916*GDISTY2)-415.5
      Where: GDISTY2=GDISTY**2
THIGH=(2.73435*GUPTH2)+
      (87.23198*LTROTIB)-1523.4
      Where: GUPTH2=GUPTH**2
LEG=(1.93834*GMXCA2)+
    (105.80362*LTIBMAL)-3616.0
      Where: GMXCA2=GMXCA**2
FOOT=(66.31667*LAKPTE)-
     (0.17967*GMNANK2)-603.6
      Where: GMNANK2=GMNANK**2

       All measures are in cms.
       Segment masses are predicted in gms.
```

REGRESSION MODEL FOR THE PREDICTION OF SEGMENT TISSUE MASSES

When any anthropometric variables for a given limb segment were regressed against the four tissue masses, i.e. skin, adipose tissue, muscle and bone, a number of artifactual predictors were identified. For example, the left arm bone mass was best predicted by two skinfolds. This was not acceptable, conceptually. Therefore specific variables were chosen as the appropriate predictors and these were regressed against the masses to obtain the predictive equations.

The variables were selected on the basis that they would be expected to reflect changes in the separate tissue masses. The selection was as follows:

1. Skin - a girth and a length.
2. Adipose Tissue - a skinfold and a length.
3. Muscle - a length and a skinfold-corrected (except in hand and foot) girth.
4. Bone - a breadth and a length.

The predictors in these regression equations, their correlation coefficients, the mean tissue masses and their standard errors are depicted in Tables 4.10 and 4.11. The abbreviations used for the variables are the same as those expanded in Appendix 5, with the omission of final "L" or "R" initials.

Table 4.10 "Best Predictors of Tissue Weights."

(Upper Limb Segments)

SEGMENT TISSUE	VARIABLE	R-SQUARED	MEAN (gm)	S.E. (gm)	SIG. OF F-RATIO
ARM					
Skin	LACRAD,GTR	0.77	107.2	19.2	0.11
Adipose Tissue	LACRAD,SFHTR	0.80	586.7	153.8	0.09
Muscle	LACRAD,CGTR	0.83	648.4	113.5	0.069
Bone	LACRAD,BEPIHU	0.85	218.1	27.2	0.057
F/ARM					
Skin	LRADSTY,GMDF	0.85	63.8	5.3	0.055
Adipose Tissue	SFHMXF,LRADSTY	0.82	181.1	49.4	0.078
Muscle	LRADSTY,CGMDF	0.87	397.8	67.5	0.045
Bone	BBISTY,LRADSTY	0.96	121.7	8.2	0.008
HAND					
Skin	LSTYDAC,GMETAC	0.43	59.5	14.6	0.42
Adipose Tissue	SFHH,LSTYDAC	0.07	77.3	21.1	0.9
Muscle	LSTYDAC,CGMETAC	0.87	112.0	18.8	0.038
Bone	BMETAC,LSTYDAC	0.92	96.5	9.6	0.02

Table 4.11 "Best Predictors of Tissue Masses."
(Lower Limb Segments)

SEGMENT TISSUE	VARIABLE	R-SQUARED	MEAN (gm)	S.E. (gm)	SIG. OF F-RATIO
THIGH					
Skin	GUPTH,LTROTIB	0.71	461.6	47.8	0.16
Adipose Tissue	LTROTIB,SFHANTT	0.88	3316.1	674.2	0.04
Muscle	CGUPTH,LTROTIB	0.84	3298.3	627.6	0.06
Bone	LTROTIB,BEPIFE	0.67	702.5	123.6	0.19
LEG					
Skin	GMXCA,LTIBMAL	0.88	129.1	20.9	0.04
Adipose Tissue	SFHMEDC,LTIBMAL	0.98	614.8	55.0	0.003
Muscle	CGMXCA,LTIBMAL	0.94	928.9	121.6	0.02
Bone	BBIMAL,LTIBMAL	0.95	463.4	32.0	0.01
FOOT					
Skin	GMETAT,LAKPTE	0.96	112.9	9.9	0.009
Adipose Tissue	GMETAT,LAKPTE	0.33	249.4	17.6	0.55
Muscle	GMETAT,LAKPTE	0.96	214.7	21.6	0.008
Bone	BMETAT,LAKPTE	0.91	265.7	33.4	0.03

The regression equations developed for each component for each segment are given in Tables 4.12 and 4.13.

Table 4.12 "Regression Equations for the Prediction of Tissue Masses in the Upper Limb Segments."

ARM	
Skin	LACRAD*7.82861 + GTR*5.44927 - 287.2
Adipose Tissue	SFHTR*24.07958 - LACRAD*14.45705 + 562.4
Muscle	LACRAD*61.84938 + CGTR*50.5674 - 2334.6
Bone	LACRAD*3.29703 + BEPIHU*68.42782 - 335.7
F/ARM	
Skin	RADSTY*2.98653 + GMDF*2.79787 - 64.8
Adipose Tissue	SFHMXF*14.8212 - RADSTY*11.13379 + 307.4
Muscle	RADSTY*32.4 + CGMDF*50.38308 - 1203.8
Bone	BBISTY*45.53836 + RADSTY*6.06379 - 277.3
HAND	
Skin	LSTYDAC*7.94449 - GMETAC*2.45104 - 36.3
Adipose Tissue	LSTYDAC*0.82875 - SFHH*3.76255 + 72.1
Muscle	LSTYDAC*18.68484 + CGMETAC*7.06078 - 339.2
Bone	BMETAC*23.62613 + LSTYDAC*6.40249 - 189.0

Table 4.13 "Regression Equations for the Prediction of Tissue Masses in the Lower Limb Segments."

THIGH	
Skin	GUPTH*3.17716 + LTROTIB*9.84859 - 85.6
Adipose Tissue	SFHANTT*170.86124 - LTROTIB*90.3672 + 4343.7
Muscle	CGUPTH*88.04496 + LTROTIB*182.25495 - 7713.9
Bone	LTROTIB*25.46116 + BEPIFE*75.53176 - 1077.3
LEG	
Skin	GMXCA*5.28041 + LTIBMAL*11.11296 - 447.4
Adipose Tissue	SFHMEDC*31.7305 + LTIBMAL*50.78751 - 1865.6
Muscle	CGMXCA*80.24425 + LTIBMAL*38.20851 - 2467.9
Bone	BBIMAL*106.40592 + LTIBMAL*20.88237 - 1052.3
FOOT	
Skin	GMETAT*2.41194 + LAKPTE*13.3227 - 242.0
Adipose Tissue	GMETAT*-2.01025 - LAKPTE*3.50251 + 370.6
Muscle	LAKPTE*27.62449 - GMETAT*2.86303 - 362.1
Bone	BMETAT*37074407 + LAKPTE*20.60686 - 519.6

BIOMECHANICAL SEGMENT PREDICTION

Except for the last anatomical model (which predicts segment tissue weights) all the above anatomical procedures were repeated on Clauser et al.'s(1969) sample to generate models for the prediction of biomechanical segment mass. Each model is presented under the appropriate subheading.

REGRESSION MODEL

The regression equations which Clauser, himself, generated were used as the regression model for this approach. They contain only PROFORMA variables and include body weight where that was shown to be a better predictor for the sample.

The predictors in these regression equations, their correlation coefficients, the mean segment masses and their standard errors are depicted in Table 4.14.

Table 4.14 "Best Predictors of Biomechanical Segment Weight." (any CLAUSER variables, n=13).

SEGMENT	VARIABLE	R-SQUARED	MEAN	STANDARD ERROR
HEAD	Body Weight, Head Girth	0.88	4729	170
TRUNK	Chest Girth, Body Weight, Trunk Length	0.99	33312	920
ARM	Body Weight, Arm Girth, Arm Length	0.96	1730	90
F-ARM	Forearm Girth, Wrist Girth	0.92	1055	60
HAND	Wrist Girth	0.86	426	30
THIGH	Body Weight, Thigh Girth	0.93	6749	450
CALF (LEG)	Calf Girth, Ankle Girth, Tibiale Height	0.98	2842	80
FOOT	Foot Length, Body Weight, Ankle Girth	0.91	959	40

The regression equations for use in predicting biomechanical segment weight are shown in Table 4.15. (Note that these regressions predict the segment weights in kilograms, therefore bodyweight must be input in kgs.)

Table 4.15 "Equations for the Prediction of segment masses (in kilos) using Clauser's 1969 Regression."

Head	(0.104*foreheadgirth) + (0.015*bodyweight) - 2.189
Trunk	(0.349*bodyweight) + (0.432*trunklength) + (0.229*chestgirth) - 35.46
Arm	(0.007*bodyweight) + (0.092*axillaryarmgirth) + (0.05*armlength) - 3.101
Forearm	(0.081*wristgirth) + (0.052*forearmgirth) - 1.65
Hand	(0.051*wristgirth) + 0.418
Thigh	(0.074*bodyweight) + (0.138*thighgirth) - 4.641
Leg	(0.111*calfgirth) + (0.047*tibialeheigt) + (0.074*anklegirth) - 4.208
Foot	(0.003*bodyweight) + (0.048*anklegirth) + (0.027*footlength) - 0.869

CALCULATION OF BIOMECHANICAL PHANTOM SEGMENT MASS VALUES

The biomechanical Phantom segment reference masses were derived in the same manner as the anatomical Phantom masses. The derived values are shown in Table 4.16.

Table 4.16 Phantom p and s values for Segmental Masses (in gms). For Biomechanical Segmentation.

Segment	p	s
HEAD	4804.0	279.0
TRUNK	27705.0	4188.09
ARM	1451.0	323.0
FOREARM	981.0	132.0
HAND	416.0	37.0
THIGH	7541.0	887.0
LEG	3334.0	390.0
FOOT	1055.0	121.0

PROPORTIONALITY/DEVIATION MODEL

The predictor variables selected for this model were the same as those for the anatomical P/D Model. The essential difference in this model is its use of the Clauser et al.(1969) sample to generate the Phantom Reference values. The Biomechanical P/D model is shown in Table 4.17. (Note that weights are processed in kilograms.)

Table 4.17 "Proportionality/Deviation Model for the Prediction of Biomechanical Segment Weight"

```
RHT = 170.18/LTOTSUS

ZHDG = (((HGFHD*RHT)-56)/1.44)
ZHDL = (((HLVERMEN*RHT)-27.27)/1.02)
MZHEAD = (((ZHDG*7)+ZHDL)/10)
PRHEAD = (((0.279*MZHEAD)+4.804)/(RHT**3))

ZSSSF = (((SFHSUB*RHT)-17.2)/5.07)
ZILSF = (((TSFHIC*RHT)-15.4)/4.47)
ZTRCH = (((TBMESOST*RHT)-27.92)/1.74)
ZABSF = (((TSFHSS*RHT)-15.4)/4.47)
ZWAG = (((TGWAI*RHT)-71.91)/4.45)
ZCHG = (((TGMESOST*RHT)-87.86)/5.18)
ZBIIL = (((TBBIILC*RHT)-28.84)/1.75)
ZTRL = (((TLC7CO*RHT)-59.97)/3.7)
ZBIAC = (((TBBIAC*RHT)-38.04)/1.92)
ZAPCH = (((DAPCHMES*RHT)-17.50)/1.38)
MZTR = (((ZCHG*7+ZBIIL+ZTRL+ZWAG-ZABSF)/9)
PRTRUNK = (((4.188*MZTR)+27.705)/(RHT**3))
```

```
ZAGR = (((GTR*RHT)-26.89)/2.33)
ZUA = (((LACRAD*RHT)-32.53)/1.77)
ZHUM = (((BEPIHU*RHT)-6.48)/0.35)
ZTPSF = (((SFHTR*RHT)-15.4)/4.47)
MZARM = ((ZAGR*7+ZUA+ZHUM-ZTPSF)/8)
PRARM = (((0.323*MZARM)+1.451)/(RHT**3))


ZWRG = (((GDISTY*RHT)-16.38)/0.72)
ZFA = (((LRADSTY*RHT)-27.77)/1.37)
ZFAG = (((GMXF*RHT)-25.13)/1.41)
MZFARM = ((ZFAG*8+ZFA+ZWRG)/10)
PRFARM = (((0.132*MZFARM)+0.981)/(RHT**3))


ZHA = (((LSTYDAC*RHT)-18.85)/0.85)
PRHAND = (((0.037*ZHA)+0.416)/(RHT**3))


ZTHG = (((GUPTH*RHT)-55.82)/4.23)
ZTHSF = (((SFHANTT*RHT)-27.0)/8.33)
ZTHIGH = (((LTROTIB*RHT)-35.44)/2.12)
ZFEM = (((BEPIFE*RHT)-9.52)/0.48)
MZTHIGH = ((ZTHG*7+ZTHIGH+ZFEM-ZTHSF)/8)
PRTHIGH = (((0.887*MZTHIGH)+7.541)/(RHT**3))


ZMCSF = (((SFHMEDC*RHT)-16.0)/4.67)
ZANG = (((GMNANK*RHT)-21.71)/1.33)
ZTIHT = (((LTIBMAL*RHT)-37.72)/2.15)
ZCAG = (((GMXCA*RHT)-35.25)/2.30)
MZLEG = ((ZCAG*8+ZTIHT*4+ZANG-ZMCSF)/12)
PRLEG = (((0.390*MZLEG)+3.334)/(RHT**3))


ZFOOTLN = (((LAKPTE*RHT)-25.50)/1.16)
PRFOOT = (((0.121*ZFOOT)+1.005)/(RHT**3))
```

Where: Weights are in kg.
Skinfolds are in mm.
All other measures are in cm.

Variables prefixed with Z indicate the variable expressed in Phantom standard deviations.
Variables prefixed with M indicate a mean value.
Variables prefixed with PR indicate a predicted weight.

BIOMECHANICAL VOLUME-BASED MODELS

The two biomechanical volume-based models were constructed in the same manner as were the anatomical ones, save for their being built on Clauser's Sample.

The correlation coefficients, mean segment masses, standard errors and F-ratio significance values for each segment prediction for the CLVOLX model are depicted in Table 4.18. (The variables are those in the equations in Table 4.19)

Table 4.18 "Statistical Details of CLVOLX Model." (Sample=CLAUSER, n=13)

SEGMENT	R-SQUARED	MEAN (gms)	STANDARD ERROR (gms)	SIG. OF F-RATIO
HEAD	0.67	4729	203	0.001
TRUNK	0.90	33312	1654	0.001
ARM	0.90	1730	100	0.001
F-ARM	0.79	1055	76	0.001
HAND	0.75	425	34	0.001
THIGH	0.81	6749	543	0.001
LEG	0.91	2842	117	0.001
FOOT	0.77	959	47	0.001

The equations for the CLVOLX Model are given in Table 4.19.

Table 4.19 "Calculation of Biomechanical Segment Mass from the Girth Squared TIMES the Length"

Head	0.04323*(Forehead girth**2)*(Vertex-Menton lgth) + 1909.0
Trunk	0.0631*(Mesosternale girth**2)*(C7-Coccyx lgth) + 1667.8
Arm	0.05725*(triceps girth**2)*(Acromiale-radiale lgth) + 214.5
F-Arm	0.05537*(forearm girth**2)*(Radiale-stylion lgth) + 60.9
Hand	0.06140*(Wrist girth**2)*(stylion-dactylion lgth) + 95.7
Thigh	0.06223*(Thigh girth**2)*(trochanterion-tibiale lgth) + 406.1
Leg	0.05828*(Calf girth**2)*(tibiale-malleolare lgth) + 688.3
Foot	0.06154*(Ankle girth**2))*(foot length) + 344.5

The correlation coefficients, mean segment masses, standard errors and F-ratio significance values for each segment prediction for the CLVOLA model are depicted in Table 4.20.
(The variables are those in the equations in Table 4.21)

Table 4.20 "Statistical Details of CLVOLA Model."
(Sample=CLAUSER, n=13)

SEGMENT	R-SQUARED	MEAN (gms)	STANDARD ERROR (gms)	SIG. OF F-RATIO
HEAD	0.67	4[illegible]9	211	0.004
TRUNK	0.91	33312	1709	0.001
ARM	0.90	1730	105	0.001
F-ARM	0.80	1055	77	0.001
HAND	0.76	425	35	0.001
THIGH	0.81	6749	574	0.001
LEG	0.92	2842	120	0.001
FOOT	0.80	959	46	0.001

The equations for the CLVOLA Model are given in Table 4.21.

Table 4.21 "Calculation of Segment Masses from the Girth squared AND the Length"

Head	(1.12577*(Forehead girth**2)) +(60.81229*Vertex-menton lgth)-154.8
Trunk	(3.37038*(mesosternale girth**2)) +(712.25837*C7-coccyx lgth)-37430.4
Arm	(1.92533*(Triceps girth**2)) +(45.53599*Acromiale-radiale lgth)-1313.5
F-Arm	(1.20675(Forearm girth**2)) +(57.35762*Radiale-stylion lgth)-1265.3
Hand	(1.42734*(Wrist girth**2)) +(6.00298*stylion-dactylion lgth)-83.4
Thigh	(2.87062*(Thigh girth**2)) +(119.57425*trochanterion-tibiale lgth) -5125.1
Leg	(2.26599*(Calf girth**2)) +(41.18498*tibiale-malleolare lgth)-915.4
Foot	(38.55287*foot lgth)+(1.47964*(Ankle girth**2)) -592.9

V. MODEL APPLICATION AND VALIDATION

This chapter is concerned with the validation of the predicting models in an independent sample and the testing of the models in three *in vivo* samples.

PERCENTAGE OF BODYWEIGHT MODELS

For many years since the advent of Dempster's model (1955), segment masses have been predicted from total body weight as a fixed percentage for each segment. This presumes a fixed relationship between the mass of each segment and total body mass for all people. It takes no more than visual inspection and a set of scales to establish that some people have proportionally larger legs and some have proportionally larger trunks for the same body weight. Therefore, the accuracy of such a model is doubtful. Yet this has been the standard approach for nearly thirty years.

In 1957, Barter generated percentage equations for segmental prediction based solely on percentage of body weight. In 1963, Fujikawa reported similarly based equations. Chandler et al. provided further predictive equations of this type in 1975. All three of these models were applied a) to the MCAS sample and b) to the CL sample to demonstrate the range of such

predictions. The results of applying the first and last of these models are displayed in table 5.1. (The results for Fujikawa's(1963) model were similar to those for Barter's(1957).)

Table 5.1 "Individual segment prediction percentage discrepancies by percent-bodyweight predictive models."

	On MiniCAS Sample.				On Clauser et al.'s Sample(1969).			
MODEL	Barter (1957)		Chandler et al.(1975)		Barter (1957)		Chandler et al.(1975)	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Total	0.9	2.1	-0.2	0.0	-0.6	1.1	-0.2	0.0
Head	8.7	10.3	-9.2	5.7	10.9	10.1	-14.6	4.0
Trunk	6.4	7.6	12.8	6.3	-5.0	4.9	4.4	4.0
L.Arm	5.5	11.6	15.9	13.6	16.1	10.8	14.2	11.7
R.Arm	3.3	12.4	12.9	16.8	16.1	10.8	10.2	12.7
L.F/Arm	32.8	18.6	28.8	16.3	15.9	11.9	6.2	10.1
R.F/Arm	41.6	18.8	26.6	14.8	15.9	11.9	5.8	11.5
L.Hand	31.7	24.4	6.9	20.2	17.0	13.6	-2.9	11.4
R.Hand	36.6	30.4	13.1	26.7	17.0	13.6	3.2	13.0
L.Thigh	-21.6	10.1	-24.6	7.6	0.6	9.5	3.4	9.7
R.Thigh	-22.7	9.7	-28.8	6.7	0.6	9.5	-0.3	9.4
L.Leg	28.2	17.9	10.8	15.0	13.7	10.2	-3.0	8.4
R.Leg	30.6	14.5	14.2	12.9	13.7	10.2	-4.3	7.9
L.Foot	12.2	23.4	-5.7	19.8	5.1	6.1	-11.0	5.2
R.Foot	12.8	20.4	-1.0	17.8	5.1	6.1	-8.5	5.3

A concession should be made in evaluating the prediction in the MiniCAS sample, since the segmentation techniques were different. For example, an error in predicting thigh segments (underprediction) would be anticipated due to the exclusion of

some of the buttock from the biomechanical thigh segment. Even so, the predictions can be seen to be considerably astray from the observed segmental masses in the CL sample. The summed total of predicted segment masses naturally is close to the observed total mass as this is predicated by the models, but it is obvious that in terms of reasonable segment mass prediction these models are not reliable. In fact, Hanavan(1964), when using Barter's equations in his own model, accepts a built-in adjustment to each segment, should Barter's equations not predict the total body mass when summed.

The only validation of this type of model is on a cadaver sample. When this is done there may be a clear indication, as in Table 5.1 of the sample specificity of these particular equations.

It is not possible to apply this type of model to an in vivo sample and use accounting for body weight as a validating criterion because of the spurious correlation with body weight inherent in this approach. So, testing of such models is not practicable. The indications for their use in in vivo samples are not favourable.

SEGMENTAL ANTHROPOMETRIC MODELS

To demonstrate the prediction given by the models proposed by this study (as opposed to "percentage of bodyweight" models), the models were applied to a number of samples. These were:

1. Sample COGRO - 896 children(male and female) aged 5 to 19.
2. Sample NA - 142 college males and females aged 19 to 29.
3. Sample BB - 66 bodybuilders(male) aged 19 to 39.

Since the study investigated the prediction of two distinct types of segmental masses, i.e. anatomical and biomechanical, the models pertaining to each type will be considered separately in their application and validation.

ANATOMICAL PREDICTION

ANATOMICAL REGRESSION MODEL

Application of the regression model developed by this study to its own sample naturally reveals it as the best predictor model for that sample (see Table 5.5), but even within its own sample the accuracy of individual segment prediction for a single individual seems to vary as can be seen from the standard deviations of the percentage difference, as shown in Table 5.2. This difficulty is inherent in small samples particularly when a limitation (choice and number) has been placed on the predictor variables.

Table 5.2 "Individual segment prediction percentage discrepancies of the anatomical regression model on its own sample"

MODEL	MCREGMC	
	mean	s.d.
Total	0.1	4.6
Head	0.3	5.6
Trunk	0.2	6.4
Arm	0.0	4.1
F/Arm	0.2	4.9
Hand	0.4	7.3
Thigh	0.1	9.6
Leg	0.0	6.0
Foot	0.3	5.9

Although the segmentation techniques of this study are not identical to those of Clauser et al. (1969), comparison of the individual segmental predictive ability of MCREGMC with that of CLREGCL revealed no significant difference on examination by the Kruskall-Wallis Test, (Conover, 1971). This test handles ordinal data of one variable pertaining to k independent samples, and tests whether all k samples are from the same population. The mean segment predictions for the two models are shown in Table 5.3 for ease of comparison.

Table 5.3 "Individual segment prediction percentage discrepancies comparison between Regression Model in their own sample"

MODEL	MCREGMC		CLREGCL	
	mean	s.d.	mean	s.d.
Total	0.1	4.6	0.1	1.2
Head	0.3	5.6	0.4	3.5
Trunk	0.2	6.4	2.6	2.5
Arm	0.0	4.1	0.6	4.9
F/Arm	0.2	4.9	0.3	5.7
Hand	0.4	7.3	0.6	8.4
Thigh	0.1	9.6	1.4	7.3
Leg	-0.0	6.0	0.1	3.0
Foot	0.3	5.9	0.4	4.5

In simple terms, the MCREG model predicts as well in the MC sample as the CLREG model predicts in the CL sample.

ANATOMICAL PROPORTIONALITY/DEVIATION MODEL

The proportionality/deviation model was applied to the MCAS sample to examine the individual segment prediction ability. The results of this application are shown in Table 5.4.

Table 5.4 "Individual segment prediction percentage discrepancies of the anatomical deviation model on its own sample"

MODEL	MCPDMC	
	mean	s.d.
Total	-0.8	4.1
Head	0.1	5.6
Trunk	1.0	5.9
Arm	0.1	7.8
F/Arm	3.6	5.6
Hand	-2.4	10.1
Thigh	-3.5	6.9
Leg	-2.0	3.9
Foot	1.3	10.2

The predictions fall within the "acceptable" range for absolute prediction, except for the hand and foot segments. Both these segments suffer from a lack of input data. All the other segments fall well within the "exceptional" 10% error criteria of Hanavan(1964), yet only the leg segment achieves the "good" criterion of this study.

ANATOMICAL VOLUME-BASED MODELS

The two volume-based models were applied to the MCAS sample to examine individual segment predictions. The results are given in Table 5.5.

Table 5.5 "Individual segment prediction percentage discrepancies of the anatomical volume-based models on their own sample"

MODEL	MCVOLXMC		MCVOLAMC	
	mean	s.d.	mean	s.d.
Total	0.1	1.7	0.0	1.6
Head	0.5	7.6	0.3	5.7
Trunk	0.2	5.3	0.2	4.5
Arm	-0.0	5.3	0.0	3.5
F/Arm	0.2	4.7	0.2	4.8
Hand	0.4	5.6	0.2	4.6
Thigh	0.2	5.0	0.0	4.6
Leg	0.3	8.3	-0.0	5.3
Foot	0.3	6.1	0.3	6.1

Nearly all segments are predicted at the "acceptable" level by both models. The mean predictions are better than by the deviation model and some are better than by the direct mass regression model. The volume-based models seem able to handle prediction of the extremities more comprehensively than does the P/D model.

COMPARISON OF THE FOUR ANATOMICAL MODELS ON THE MCAS SAMPLE

Analysis of all four of the above models on the MiniCAS sample by the Repeated Measures Test(Hull and Nie,1981) showed no significant difference between any of the models in predictive ability. This was confirmed by the Friedman Test(Hull and Nie,1981). This was as expected, since the models were all derived from this sample.

MODEL VALIDATION

The above applications, of both the anatomical and the biomechanical segment prediction models, to their own estimating samples do not provide direct validation of the ability of the models to predict segment masses in larger or different populations. As mentioned, the ability of a model to predict in its estimating sample is expected. The prediction, based on the mean values for the sample may not be perfect for the individual subjects, but, in general (if there is any relationship between two or more parameters) will be satisfactory for nearly all subjects in the estimating sample.

The ability of a model to account for total bodyweight is, as discussed in Chapter I, an indication of the accuracy of the model in predicting segment weight, but no more than an indication - more useful as a means of comparing one model with another, rather than checking the accuracy of the segment weight prediction.

The only true validation of the segment predictive ability of the models is by application to an independent cadaver sample. This poses a problem if no data from such a sample is available. This study utilises two independent cadaver samples, but the segmentation techniques employed were different for the two samples, (as discussed in both Chapters I and II). Application of the models built on one sample, to the other sample, could provide an indication of segment prediction

adequacy, if technique differences were taken into account when examining the resultant predictions.

APPLICATION OF MODELS TO OPPOSING CADAVER SAMPLES

Based on the segmentation technique differences, i.e. the planes of the cuts delimiting the segments, the MC models would be expected to demonstrate the following prediction trends in the CL sample.

1. Head - similar.
2. Trunk - underprediction.
3. Arm - slight overprediction.
4. Forearm - underprediction.
5. Hand - slight overprediction.
6. Thigh - substantial overprediction.
7. Leg - underprediction.
8. Foot - slight overprediction.

To gain further insight into these differences, the mean segment weights of the two samples were expressed as percentages of total bodyweight and compared.

The calculated values of these derived parameters are given in Appendix 8. Table 5.6 shows the mean percentages.

Table 5.6 "Comparison of segment weights expressed as percentages of total bodyweight in the two cadaver samples.

	WATBBDI	PERHEAD	PERTRUNK	PERARM	PERFARM
MCAS:	57608.3	7.32	46.16	2.71	1.33
CL:	66517.9	7.18	49.99	2.60	1.59

	PERHAND	PERTHIGH	PERLEG	PERFOOT
MCAS:	0.62	13.41	3.69	1.51
CL:	0.64	10.13	4.29	1.45

The hand is the only segment where the comparison of the percentages did not confirm the technique expectation. This either indicates that the CL sample was bigger handed than would be expected or that the MCAS sample was smaller handed.

Apart from this, if these mean percentages are accepted as a reasonable estimate of the technique differences, MC models would be expected to demonstrate differences in predicting segment weight in the Cl sample of approximately the following magnitude.

1. Head - plus 2% (i.e overpredict CL head segment by 2%)
2. Trunk - minus 8%
3. Arm - plus 4%
4. Forearm - minus 20%
5. Hand - plus small%
6. Thigh - plus 25%
7. Leg - minus 16%
8. Foot - plus 4%

The reverse of these predictions would be expected when the CL models are applied to the MCAS sample.

Each of the anatomical prediction models (MCREG, MCPD, MCVOLX, MCVOLA) was applied to the CL sample and each of the biomechanical prediction models (CLREG, CLPD, CLVOLX, CLVOLA) was applied to the MCAS sample.

The results of applying MC models to the CL sample are given in Table 5.7.

Table 5.7 "Individual segment prediction percentage discrepancies of the anatomical models predicting in the CLAUSER sample"

MODEL	MCREGCL		MCPDCL	
	mean	s.d.	mean	s.d.
Total	-2.5	4.1	-0.2	3.4
Head	-1.0	6.4	-2.3	5.0
Trunk	-10.1	6.7	-9.2	4.0
Arm	6.5	7.5	17.1	9.2
F/Arm	-2.4	6.7	3.9	7.4
Hand	2.4	13.1	8.1	15.8
Thigh	25.0	11.2	32.1	11.5
Leg	-13.2	6.4	-18.7	4.0
Foot	0.9	10.1	8.5	12.6

MODEL	MCVOLXCL		MCVOLACL	
	mean	s.d.	mean	s.d.
Total	-3.8	2.7	-2.8	3.4
Head	-7.2	4.5	-1.2	6.4
Trunk	-12.6	4.1	-11.3	5.1
Arm	5.1	6.3	6.1	6.7
F/Arm	-4.0	6.1	-1.8	7.0
Hand	9.2	10.1	6.6	10.5
Thigh	29.9	10.1	28.5	10.2
Leg	-20.4	4.3	-18.1	6.4
Foot	1.6	11.0	1.6	11.0

Examination of Table 5.7 supports the direction of the predicted differences. If the mean segment weight predictions are adjusted to take into account the systematic differences due to technique, Table 5.7 can be rewritten as Table 5.8. (The hand segment was not adjusted).

Table 5.8 "Individual ADJUSTED prediction percentage discrepancies of the anatomical models predicting in the CLAUSER sample"

MODEL	MCREGCL		MCPDCL	
	mean	s.d.	mean	s.d.
Total	-2.5	4.1	-0.2	3.4
Head	-3.0	6.4	-5.3	5.0
Trunk	-2.1	6.7	-1.2	4.0
Arm	2.5	7.5	13.1	9.2
F/Arm	18.4	6.7	23.9	7.4
Hand	2.4	13.1	8.1	15.8
Thigh	0.0	11.2	7.1	11.5
Leg	3.2	6.4	-2.7	4.0
Foot	-4.9	10.1	4.5	12.6

MODEL	MCVOLXCL		MCVOLACL	
	mean	s.d.	mean	s.d.
Total	-3.8	2.7	-2.8	3.4
Head	-9.2	4.5	-3.2	6.4
Trunk	-4.6	4.1	-3.3	5.1
Arm	1.1	6.3	2.1	6.7
F/Arm	16.0	6.1	19.8	7.0
Hand	9.2	10.1	6.6	10.5
Thigh	4.9	10.1	3.5	10.2
Leg	-4.4	4.3	-2.1	6.4
Foot	-3.6	11.0	-3.6	11.0

Examination of Table 5.8 reveals that few of the predictions, of the MC models in the CL sample, come within the "acceptable" criterion. No segments were predicted within this range of individual segment prediction by MCREGCL. MCPDCL achieved this range for the head, trunk and leg segments only. MCVOLXCL predicted only trunk, arm and leg segments "acceptably". MCVOLACL predicted only trunk and arm segments within this range.

The prediction of the forearm had the largest mean discrepancy for all four models. This would seem to indicate either a discrepancy in one or more of the predicting variable definitions from within the CL sample, resulting in non-equivalence of the variable(s) used in the prediction, or an inappropriate adjustment factor.

Although the models cannot be said to be validated according to the criteria established in Chapter I, the predictions were all in the directions anticipated by the technique differences. It should be recognised that the adjustment factor was based on the mean percentages of the two samples, increasing the chance of a predictive error in the individual. This increased error may well have been sufficient to push most of the predictions outside the criterion range.

To examine whether this large variation in prediction was unique to the MCAS sample, or whether the cross-technique comparison was increasing the predictive error, the reverse procedure, of applying the CL models to the MCAS sample was performed.

The results, with adjustment for technique differences included, are shown in Table 5.9

Table 5.9 "Individual ADJUSTED prediction percentage discrepancies of the biomechanical models predicting in the MCAS sample"

MODEL	CLREGMC		CLPDMC	
	mean	s.d.	mean	s.d.
Total	0.6	2.1	-3.5	2.7
Head	8.8	7.4	5.1	8.0
Trunk	5.0	6.5	1.4	6.5
Arm	-8.8	9.5	-17.3	19.8
F/Arm	-23.5	6.6	-21.8	3.6
Hand	0.4	10.3	2.4	6.1
Thigh	-1.2	8.7	-6.5	13.3
Leg	8.7	16.4	5.5	4.8
Foot	15.3	23.1	-1.8	14.2

MODEL	CLVOLXMC		CLVOLAMC	
	mean	s.d.	mean	s.d.
Total	-0.7	1.5	-1.6	1.9
Head	12.9	8.6	9.9	8.0
Trunk	3.1	5.9	3.0	7.4
Arm	-6.4	8.2	-6.6	8.7
F/Arm	-20.3	4.6	-31.6	10.7
Hand	-3.5	8.2	-2.4	9.8
Thigh	-4.9	9.5	-6.9	11.3
Leg	8.1	10.9	7.9	12.0
Foot	17.0	25.1	13.3	23.5

Examination of these results indicated that the CL models predicted poorly in the MCAS sample when compared to MC models predicting in the CL sample. The only segment to be "acceptably" predicted was the trunk segment and that was only by one model, i.e. CLPDMC. Nevertheless, the direction of technique differences was confirmed and the magnitude of the adjustment seemed to be reasonable, at least in the major segments of head, trunk and thighs.

The mean forearm predictions once again stood out as being widely discrepant from zero for all four models. This appears to

confirm the suspected variable differential, and/or that the adjustment factor used for this variable was not the appropriate one.

APPLICATION OF MC MODELS TO CAS DATA (1979/80)

Although the Cadaver Analysis Study (CAS) of Clarys et al. (1984) did not segment the limbs at the elbow, wrist, knee or ankle joints, segmentation was carried out at the shoulder and hip joints by the same technique as used in the MCAS sample. (Duplicating the CAS technique was one of the deciding factors in the MCAS technique selection at both the hip and the shoulder, as discussed in Chapter I.) The CAS data, therefore, included weights for the whole upper and lower limbs.

It was thus possible to apply a further validation test of the MC models by applying them to the CAS sample, predicting segment weights, and then summing the limb segment predictions to estimate the whole limb weight. This estimate could then be compared to the observed whole limb weight.

The neck was not segmented in the same plane in both studies. The CAS sample had the neck associated with the head segment, whereas the MCAS sample had the neck associated with the trunk segment. Therefore the predictions of these two segments were combined to estimate head AND trunk as a single unit. This was then compared to the observed weight of the combined unit.

The means, standard deviations, maxima and minima of the percentage discrepancies of the MCREG segment predictions in 23 CAS subjects, for the head and trunk, upper limb, and lower limb segments are shown in Table 5.10. The individual predictions for the same parameters are shown in Appendix 9.

Table 5.10 Application of MCREG and BARTERreg to CAS Data.

	MCREG			BARTERreg
	PDHDTR (n=21)	PDUL (n=23)	PDLL (n=23)	PDUL (n=23)
Mean	-3.7	-5.1	-7.2	10.6
S.D.	8.7	8.2	6.6	9.9
Minima	-25.1	-18.2	-19.6	-3.8
Maxima	12.4	26.2	5.3	32.2

Where: PDHTR is the percent discrepancy of the combined head and trunk.
PDUL is the percent discrepancy of the upper limb.
PDLL is the percent discrepancy of the lower limb.

These results fell within the "acceptable" range (of 95% of the sample predicted within 15% of the observed segment weights) in the head and trunk segment. However this "acceptable" prediction target was only narrowly missed overall. In the head and trunk segment, 20 (of 21) subjects (95%) were predicted within 15% and 15 (71%) were predicted within 10%, the "good" level.

In the upper limb, 21 (91%) were predicted at the "acceptable" level and 18 (78%) at the "good" level.

For the lower limb region, the predictions were "acceptable in 20 out of 23 (87%) and "good" in 16 (70%).

The overall prediction for the three segments revealed 61 out of 67 segments predicted within 15% of the observed values. This represents 91% of the sample. This is an acceptable validation of the MCREG model in an independent sample. Barter's(1957) model was only able to predict 68% of the segments within 15% in Clauser et al.'s(1969) sample.

The other three MC models were also applied to the CAS sample. The individual segment predictions are given in Appendix 10. The summary results are given in Table 5.11.

Table 5.11 "Application of MCPD, MCVOLX and MCVOLA models to the CAS sample."

	PDHDTR	PDUL	PDLL
MCPDCAS			
Mean	-5.5	-3.1	-15.0
S.D.	5.8	6.4	6.6
Min.	-13.9	-14.6	-25.8
Max.	4.5	12.3	-1.8
MCVOLXCAS			
Mean	-1.3	-7.8	-13.2
S.D.	7.9	4.2	5.4
Min.	-14.4	-16.9	-22.8
Max.	14.8	-0.1	-4.1
MCVOLACAS			
Mean	-2.7	-7.1	-11.3
S.D.	7.4	4.2	5.1
Min.	-18.0	-16.7	-19.0
Max.	11.7	1.7	-3.6

The predictions in all three models were on a par with the predictions by MCREGCAS, except in the lower limb segments. The

MCVOLX model predicted 100% of the head and trunk, and upper limb segments within 15%, and, overall, predicted 84% of the segments within 15%.

The MCVOLA model also predicted 84% of all segments within 15%, with predictions in the head and trunk, and upper limb segments, at this level, of 94% and 96% respectively.

The MCPD model did not fair quite as well, predicting only 70% of all segments within 15%, but predicted 100% of the head and trunk segments at the "acceptable" level and 71% of the upper limb at that level. Thee appears to be a systematic underprediction in the lower limb by these three models. This underprediction could be explained by a technique difference in the measures taken in the CAS sample for the thigh and leg lengths. No correction was made for this in calculating the above predictions, but there is no doubt that this affected the overall percentage of "acceptable" prediction considerably.

APPLICATION OF BARTER'S(1957) REGRESSION TO THE CAS SAMPLE

The regression equations from Barter(1957) were also applied to the CAS sample to verify that the MC model predictions were at least as good as a currently-accepted model. Since there was a technique-dependent discrepancy in trunk and thighs due to the segmentation at the hip, (Dempster,1955 cf. Clarys et al.,1984) only the prediction of the upper limb was considered. The difference in technique at the shoulder was

minimal.

The individual predictions for this parameter are given in column four of the table in Appendix 9. The means, standard deviations, maxima and minima are shown in the 4th column of Table 5.10.

Barter's equations do not achieve the "acceptable" level of prediction, predicting slightly less well than the MCREG model. 17 out of the 23 subjects were predicted at the "acceptable" level (74%), and 11 (48%) were predicted at the "good" level.

A t-test (Ferguson,1976) was applied to the prediction of the upper limb by both MCREG and Barter's model, to test the significance of the difference between two means for correlated samples. The result showed the MCREG prediction to be significantly better at the 0.1% level, easily achieving the "good" criteria defined in Chapter I.

The test was repeated for each of the other three MC models (comparing them to the Barter model). Both MCVOLX and MCVOLA were significantly better at the 0.1% level also. The MCPD model demonstrated no significant difference.

This comparison reinforces the conclusion to accept the MCAS cadaver sample as a basis for predictive models of segment weights, and confirms the acceptance of the generated models. On the independant sample(CAS), three of the models showed that they predicted significantly better than the percentage-of-bodyweight model and the fourth predicted as well. The models achieved these levels of prediction through segmental

anthropometry alone, whilst at the same time accounting for total body weight without reference to that parameter.

IN VIVO APPLICATION OF ANATOMICAL PREDICTION MODELS

The anatomical models were applied to three *in vivo* samples measured by the Simon Fraser Kinanthropometric Research Unit. These were:

1. Sample COGRO - 896 children(male and female) aged 5 to 19.
2. Sample NA - 142 college males and females aged 19 to 29.
3. Sample BB - 66 bodybuilders(male) aged 19 to 39.

Since it was not possible to test the accuracy of the individual segment predictions due to the *in vivo* nature of the sample, the adequacy of the prediction was based on the sum of the predicted segments equalling the observed body weights. This is a reasonable tactic for the purposes of comparing models since bodyweight was not a predicting parameter in any of them.

The means and standard deviations of the percentage differences of predicted versus observed body weights for the four models on each of the four samples are displayed in Table 5.12. (The cadaver sample predictions have been included here as well for ease of comparison.)

Table 5.12 "Means and standard deviations of the percentage discrepancy between predicted and observed bodyweight for the four anatomical models models on each of four samples."

Model	MCREG		MCPD	
Sample	mean	s.d.	mean	s.d.
MC n=6	0.1	4.6	-0.7	4.1
CO n=896	4.6	7.7	2.1	5.4
NA n=142	3.1	6.5	2.2	5.8
BB n=66	13.1	6.9	7.8	3.4

Model	MCVOLX		MCVOLA	
Sample	mean	s.d.	mean	s.d.
MC n=6	0.1	1.8	0.0	1.6
CO n=896	6.0	7.4	-0.8	7.4
NA n=142	0.8	4.9	1.5	5.1
BB n=66	7.2	4.0	13.6	5.5

To clarify the question of which model gave the best prediction, all models were subjected to the Repeated Measures Test for 1-way Analysis of Variance of the difference of the means for the percentage predicted difference, for each sample. The results of this analysis are shown in Table 5.13.

Table 5.13 "Results of Repeated Measures analysis of four anatomical models applied to four samples."

Sample	Best Model	
MCAS	None significant at 5%	
COGRO	MCVOLA	(sig. < 0.1%)
NEWADULT	MCVOLX	(sig. < 0.1%)
BODYBUILDER	MCVOLX	(sig. < 3.0%)

Table 5.13 shows that the best choice for predicting anatomical segment mass in adults is the volume-based model using a single compound predicting variable, i.e. the squared girth multiplied by the length of the segment being predicted. One feature of this model is that it has the correct dimensionality resulting from its compound variable.

In children, the volume-based model with the girth squared and the length as distinct variables gives a greater opportunity to explain the variance across the age range. The proportionality/deviation model proved to be the second best predictor in both the COGRO and BB samples.

The predictions of MCVOLA and MCPD, in COGRO were examined by age group. This comparison is given in Appendix 11. The MCVOLA model, whilst significantly better over the whole sample, did not predict the younger age groups as well as it did the older ones. The MCPD model, however, predicted uniformly well

irrespective of the age group. For this reason, the MCPD model may well be preferred for predicting in child samples.

BIOMECHANICAL PREDICTION

BIOMECHANICAL REGRESSION MODEL

Clauser et al.'s(1969) regression was applied to their own sample to verify the individual segment prediction. This application was included here to obviate the need to refer to Clauser et al.'s(1969) publication solely for this purpose. The predictions are as shown in Table 5.14.

Table 5.14 "Individual segment prediction percentage discrepancies of the biomechanical regression model on its own sample"

MODEL	CLREG	
	mean	s.d.
Total	0.1	1.2
Head	0.4	3.5
Trunk	2.6	2.5
Arm	0.6	4.9
F/Arm	0.3	5.7
Hand	0.6	8.4
Thigh	1.4	7.3
Leg	0.1	3.0
Foot	0.4	4.5

It should be remembered that this model was developed by Clauser et al. (1969) and is not a product of this study. Its consideration here provides a valuable basis for comparison for the other three biomechanical segment predicting models which were developed, and a useful comparative device for evaluating the anatomical segment predicting models as well.

Based on the criteria of this study, the predictions only achieve the "satisfactory" level (prediction of individual segments within 15% for 95% of the sample) in half the segments. These results give a clear indication of the general level of predictability (within segments) of a "currently accepted" model. The comparison of the ability of the CLREG model to predict in sample CL compared to the ability of the MCREG model to predict in sample MC showed no significant difference between the two models (at the 0.05 level, as examined by the Kruskal-Wallis Test(Conover, 1971) for the comparison of means of independent samples.) as discussed earlier in this chapter.

BIOMECHANICAL PROPORTIONALITY/DEVIATION MODEL

The biomechanical proportionality/deviation model was applied to the Clauser sample to examine the individual segment prediction ability. The results of this application are shown in Table 5.15.

Table 5.15 "Individual segment prediction percentage discrepancies of the biomechanical deviation model on its own sample"

MODEL	CLPDCL	
	mean	s.d.
Total	-1.0	3.2
Head	2.4	4.8
Trunk	-1.6	4.3
Arm	2.8	6.2
F/Arm	0.9	6.9
Hand	7.4	14.4
Thigh	3.2	8.1
Leg	3.4	5.3
Foot	3.5	13.2

Predictions were "acceptable" only in the head, trunk and leg segments. The hand and feet predictions are more disparate than the other segments, again most probably as a function of the limited data variables available for the predictions in these extremities.

BIOMECHANICAL VOLUME MODELS

The two biomechanical volume-based models were also applied to their estimating sample to examine individual segment predictions. The results are shown in Table 5.16.

Table 5.16 "Individual segment prediction percentage discrepancies of the biomechanical volume-based models on their own sample"

MODEL	CLVOLXCL		CLVOLACL	
	mean	s.d.	mean	s.d.
Total	-1.3	2.6	-1.3	2.4
Head	0.1	4.2	0.1	4.1
Trunk	0.2	4.6	0.2	4.4
Arm	0.3	5.8	0.3	5.8
F/Arm	0.4	6.4	0.3	6.3
Hand	0.6	8.7	0.6	8.3
Thigh	0.4	7.5	0.4	7.7
Leg	0.2	4.4	0.2	4.3
Foot	0.2	5.2	0.2	4.8

Individual segment predictions were "acceptable" in all but the hand and thigh segments. Head, trunk and leg predictions were "good". The mean segment predictions in both models are very pleasing, particularly in the light of the uniform smallness of the standard deviation.

Analysis of the predictions of all four biomechanical prediction models on their estimating cadaver sample, by the

Repeated Measures Test, revealed no significant difference between any of the models in predictive ability for this sample. Again, this was to be expected since all four models were estimated on this sample.

IN VIVO APPLICATION OF BIOMECHANICAL PREDICTION MODELS

All four biomechanical models were then applied to the same three *in vivo* samples as were the anatomical models. The same criteria were used in this application also.

The mean and standard deviation of the differences of predicted versus observed body weights for the models on each of the four samples are displayed in Table 5.17. (The cadaver sample predictions have also been included.)

Table 5.17 "Means and standard deviations of the percentage differences of predicted versus observed bodyweight of the biomechanical predicting models on each of four samples."

Model	CLREG		CLPD	
Sample	mean	s.d.	mean	s.d.
CL n=13	0.1	1.2	-1.0	3.2
CO n=896	-4.0	13.6	-0.2	5.3
NA n=142	4.2	2.7	1.3	5.7
BB n=66	8.4	2.4	22.7	3.8

Model	CLVOLX		CLVOLA	
Sample	mean	s.d.	mean	s.d.
CL n=13	-1.3	2.6	-1.3	2.4
CO n=896	7.0	6.7	-13.8	14.8
NA n=142	3.0	4.9	-3.2	4.9
BB n=66	10.5	4.3	6.5	5.0

The four models and samples were subjected to the Repeated Measures Test for 1-way Analysis of Variance of the difference of the means for the percentage predicted difference. The results of this analysis are shown in Table 5.18.

Table 5.18 "Results of Repeated Measures analysis of four biomechanical models applied to four samples."

Sample	Best Model	
CLAUSER	None significant at 5%	
COGRO	CLPD	(sig. < 0.1%)
NEWADULT	CLPD	(sig. < 0.1%)
BODYBUILDER	CLVOLA	(sig. < 0.1%)

The results of this analysis shows the P/D model as the best predictor in both CO and NA samples. As was seen in the application of the anatomical models to the <u>in vivo</u> samples, there was no model which predicted best in all samples, though the P/D model was preferred (in that it was as good as, or better than, the other models in three of the four samples). The biomechanical predictions also reflect sample specificity.

VI. CONCLUSION

The final chapter discusses the results of the study and considers the acceptance and application of the generated models.

The investigation of segmental mass properties of the human body is no simple task. Current technology does not readily permit measurement of this parameter *in vivo*. Therefore, measurements must be made on the dead and relational information extrapolated to the living.

The theme of this study has been that the accepted method of prediction - considering the segment weight as a fixed percentage of the total body weight (with all the concomitant assumptions that entails) - is not as good as the prediction from segmental anthropometry. The "percentage" method has been used from the time of Harless(1860) right through to Chandler et al.(1975). The only model to emerge during that period which used segmental parameters for predicting segment mass was that of Clauser et al.(1969). Even the mathematical models of Whitsett(1962), Gray(1963) and Hanavan(1964) used a "percentage" method to determine segment mass, despite using segmental anthropometry to predict segment volume.

The continued use of this "percentage" tactic today, highlights the general acceptance that this type of model enjoys. Despite its not being a good predictor of individual

segment mass when applied to non-estimating cadaver samples, many investigators are prepared to regard it as an acceptable predictor. In addition, this type of model always accounts for total body weight, obviating any failure to do so which might call into question the segment prediction accuracy.

To examine the hypothesis of this study, that:

> "differences in segmental anthropometry will reflect differences in segment composition, giving an improved estimate of segment mass compared to a prediction based on a percentage of body weight"

a cadaver sample was segmented and four models were developed. These models were then validated against an independent cadaver sample, before being tested on three _in vivo_ samples. A unique segmentation technique resulted in "anatomical" segments being delineated. Thus the models generated from this sample predicted "anatomical" segments.

In parallel, using the raw data from Clauser et al.'s(1969) study, three "biomechanical" segment predicting models were developed. These three models, plus Clauser et al.'s(1969) own regression model, were tested in the three _in vivo_ samples.

The four anatomical models will be discussed first.

ANATOMICAL PREDICTION

Six cadavers were subjected to an extensive battery of anthropometric measures, segmented, and their segments weighed both in air and under water. Anthropometric measures were regressed against the segment masses and equations developed to predict segmental mass from segmental anthropometry.

Model Development

Four regression models were developed which predicted "anatomical" segment mass.

These were:

1. The REG model - predicting segment mass as a direct regression from segmental anthropometry (one or two predicting variables).
2. The PD model - predicting mass as a deviation from a reference mass by examining the deviation of segmental anthropometry from reference segmental anthropometric values.
3. The VOLX model - predicting mass by regression from a combined variable which was derived by multiplying the squared girth of the segment by its length.
4. The VOLA model - predicting mass by regression from two segmental variables, a squared girth and the length.

In addition, regression equations were generated to predict segment tissue masses from intra-segmental anthropometry.

Model testing on the Estimating Sample

The four models were applied to the cadaver sample from which they were estimated and their ability to predict individual segment masses was examined. Though none of the models achieved the criterion, of predicting all segments within 10% in 95% of the sample, that had been hoped for, it seems clear, particularly in the light of the predictions of extant models in their own samples, that such a criteria had been an overly ambitious one and that the results achieved can be regarded as being positive.

Cross-technique Prediction

The ability to predict in an estimating sample is not a validation of a model. Application of the model to an independent sample is necessary. The only independent sample for which data were available on 14 segments was that of Clauser et al. (1969). The segmentation techniques for this sample were widely different in some segments.

In order to validate the anatomical models, an attempt was made to quantify the differences due to technique and then

predict segment masses with the anatomical models in the biomechanical sample and vice versa.

The four anatomical models were applied to the Clauser et al.(1969) sample and an adjustment was made to the individual segment predictions based on the differences between the segment mean percentage of body weight values obtained in the two samples. Similarly, the four biomechanical models were applied to the MiniCAS sample and adjustments were made in the opposite direction. The results of the eight applications were then examined.

Analysis of the results using a Repeated Measures Test showed no significant difference between the predictions of the various models. None of the models achieved prediction criterion levels of "acceptable" in all segments. Indeed, only one of the biomechanical models even predicted a single segment at this level. The predictions of the models were, however, as good as the predictions of an accepted "percent-of-bodyweight" model (Chandler et al.'s 1975 regression) in a same-technique sample (the Clauser et al.(1969) sample).

It is difficult to judge to what extent tolerance should be allowed for probable failure to compensate sufficiently for technique differences. At best, the application of the anatomical models confirmed that their predictions are as good as accepted models in an independant sample. The first biomechanical model(CLREG) already enjoys acceptance in the field. The results of this study show models(CLPD, CLVOLX and

CLVOLA) as equally good predictors within a cadaver sample.

Application of MC models to the CAS sample

Further confirmation of the anatomical models was sought by applying them to the fractionated cadaver sample of Clarys et al.(1984). The only segments in the CAS sample which paralleled those in the MiniCAS sample, were those of the head-and-trunk, upper limb and lower limb. It was felt that a valid comparison could be made in terms of predicting those three combined segments by predicting and summing the segments which constituted them. This was done for the 23 subjects in the CAS sample.

Based on the validation criteria set out at the beginning of this study, the prediction of 93% of the combined segments within 15% of their observed values, by the MCREG model, appears to be a clear confirmation of the validity of applying models built on the MiniCAS sample to other samples. The equally good prediction in the head-and-trunk and upper limb segments by the other three models, and their acceptable systematic underprediction in the lower limb segments (due to length measurement technique differences), confirmed the adequacy of their use also.

Comparison with Barter's Prediction in the CAS Upper Limb

A final test as to the adequacy of the anatomical models was conducted by applying the regressions of Barter(1957) to the CAS sample to predict the mass of the total upper limb. The predictions obtained were then compared serially with the MCREG, MCPD, MCVOLX and MCVOLA predictions of the same parameter, using Student's t test. The superiority of the three MC models at the 0.1% level confirmed their acceptance as predictors in independant samples.

In vivo application of models

Following the establishment of the acceptability of individual segment prediction by the anatomical models, the models were then applied to a number of in vivo samples and examined on the basis of their ability to account for total body weight.

The second volume-based model (girth squared and a length) proved to be the best predictor in the sample of 896 children aged 5 to 19, followed by the proportionality/deviation model. The PD model, however, showed a more uniform prediction at younger age levels. The first volume-based model (girth squared times a length) proved to be the best predictor in the two in

vivo adult samples.

The results of these applications do not reveal any single model as the best overall. The absence of a clearly superior model suggests an interaction between the models and the sample being tested. The sample appeared to be closer to the estimating sample in some parameters (i.e. those used as predictors in the particular model) than in others. As a result it appears more appropriate to recommend the use of the model which performed best in the sample in this study closest to the sample which an investigator wants to examine.

BIOMECHANICAL PREDICTIONS

A parallel development, application and analysis of biomechanical segment prediction models was enabled by the granting of access by Charles Clauser to their 1969 cadaver data.

In addition to Clauser et al.'s(1969) own regression model, three models were developed to predict biomechanical segment mass which corresponded to the proportionality/deviation and volume-based models of the anatomical phase of the thesis. The same series of procedures was carried out, the only difference being the use of Clauser et al.'s(1969) sample as the estimating sample.

When applied to their estimating cadaver sample, none of the four biomechanical models showed any significant

superiority, over the other three, in prediction of the individual segment masses. Comparison with percentage of body weight predicting models, however, showed all four of these models to be significantly better at the 1% level. Since Clauser et al.'s(1969) regression model(CLREG) uses bodyweight as a predictor, this result confirms the quality of bodyweight as a predictor in an estimating sample, whilst at the same time confirming the inappropriateness of its use in a non-estimating sample.

Individual predictions were good for all models but (as for the anatomical prediction models) did not reach the criteria, of predicting all segments within 10% in 95% of the sample, aimed at.

The four models were applied to the MCAS sample with the results as discussed earlier in this chapter. The CLREG model needs no validation by this study as it has long been accepted in the field of biomechanics as a segment predictor. The cross-technique application confirmed the ability, however, of the three biomechanical models developed in this study (CLPD, CLVOLX and CLVOLA), to predict individual segments equally as well as the CLREG model.

The four models were then applied to the three <u>in vivo</u> samples.

In both the child and young adult samples, the proportionality/deviation model was significantly superior in accounting for total body weight (as an extrinsic evaluation of

segment prediction accuracy). It was not, however, as good in predicting in the bodybuilder sample as was the first volume-based model(girth squared and a length) or Clauser's regression model.

Recommendations about the choice of a biomechanical model are the same as those made with reference to the anatomical models, since the interaction of model and sample is also apparent in this phase of the thesis. Therefore, again, it is felt that it is more appropriate for an investigator to choose the model which performs best on the sample most closely approximating the sample that is to be examined.

ACCEPTANCE OF MODELS

The models are acceptable for the following reasons:

1. The MC models predict anatomical segment mass, as defined earlier, - a feature of no other segmental model. This is a contribution to the area of segmental analysis, providing an alternative to the "link" segment approach of the biomechanists.
2. The segmental tissue mass regression models provide a first estimate of segment composition which is unique in the literature.
3. The PD, VOLX and VOLA models, both anatomical and biomechanical, are significantly better in normal young

adults and children, in predicting what they claim to, than are direct regression models built from the same sample.

4. The PD, VOLX and VOLA models (and the REG model for anatomical prediction) do not use body weight as a predicting variable. This not only confirms that segmental predictors are as good as, or better than total bodyweight in reflecting segment composition, but also permits the use of bodyweight as an indirect validation of the segment predictions.

5. Models of this type permit the introduction of body weight as a final adjustment, (the discrepancy between predicted and observed body weight being distributed proportionally across the segments), without jeopardizing the use of body weight as an indirect validation procedure.

The models should be employed with caution, however. Due to the inability to achieve a prediction in individual segments of better than 5% in 95% of the cadaver samples, reservations are expressed as to the use of these models for other than group comparisons. It is appropriate, here, to echo Clauser et al.'s words at the conclusion of their 1969 report:

> "the predictive equations developed in this study are believed to provide a better estimate of weight of segments of the body for individuals and populations than were previously available. They should not, however, be considered as other than good first approximations until they can be adequately validated on live populations" [1]

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[1] Clauser et al. (1969), page 61.

APPLICATIONS

The major applications of the anatomical models will be to encourage the use of anthropometry to assess segmental mass characteristics for the appraisal of normal growth status. Used in longitudinal designs, the models can be related to changing patterns associated with genetic and environmental influences, including exercise, diet and specific treatment modalities. The human design and individual variation can be appraised by lengths, breadths, girths and skinfold thicknesses. Properly integrated, they can reconstruct both segmental and tissue masses which describe the theatre for the physiological events which characterise movement and life itself.

The biomechanical models will provide a better method for estimating segmental mass for understanding human locomotion and the needs for ergonomic engineering. The applications in this area are many and the need has been long recognised (Hanavan, 1964).

The provision of equations for the prediction of tissue components within limb segments is an important advance in the area of cadaver analysis application. Until 1980, nearly all cadaver studies had been concerned with the mass of total segments and not their internal compositional masses. In 1980, Clarys et al.(1984) conducted what was, perhaps, the most comprehensive compositional dissection ever. The work of this study has added to the establishment of Clarys as one of the

foremost compositional analyst in the world. This study only presents component regressions for the limb segments, but the data are now available from the major study which will permit calculation of the trunk components as well, (a project being undertaken by others.).

FUTURE RESEARCH

Several directions are indicated for future research in the area. Time and money did not permit the use of fresh cadavers for this project. The use of embalmed cadavers in this study was based on the assumption that tissue changes after demise are matched by changes in anthropometry such that the relationship of one to the other is fundamentally unaltered. Whereas the models are acceptable in their present form for group comparisons, the use of fresh cadavers may enable an improved model to be developed for individual prediction, since both anthropometry and tissues may more closely approximate the in vivo situation. Obviously this has to be a long term goal due to cost and cadaver availabilty.

Further, the predictive value of the model will be improved, by a more heterogeneous sample which represents as wide a range of subjects as possible. The great advantage of the segment anthropometric model is that it can only be enhanced by improved anthropometric techniques, e.g. improved skinfold measurement, and more comprehensive data assembly. The

"percentage-of-bodyweight" model has no room for improvement, except perhaps by the use of much larger samples.

There is a clear need for more analysis in the younger age groups to more closely approximate the compositional status of the living, in particular those who are more active. Of course, this may never be achievable, since young healthy people do not normally die without debilitation or trauma. Computerised Axial Tomography may be one solution to the problem, but cadaver validation is still needed initially with this procedure and the costs are virtually prohibitive at the present time.

The above suggestions are, basically, improvements on the existing research in terms of more comprehensive sampling or better material. A more exciting direction that presents itself is the development of the models, both in terms of segment mass and segment composition prediction further across the biological continuum, firstly to other primates and then to other mammals.

Many, animal dissections have been carried out, but little or no anthropometry has been done beforehand. If sufficient animal data (anthropometric and cadaver) can be obtained, and a valid segment mass prediction model constructed, then compositional changes in animals can be studied without sacrificing the animals being studied, and significant advances can be made in monitoring nutritional and exercise effects in such animals.

The models developed in this study are important conceptual tools which will promote the development of a general segmental

prediction model applicable across the species. In doing so they will be a medium for the integration of human and animal biology and will further develop the essential links between anthropometry, quantitative anatomy and functional morphology.

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APPENDIX 1 - DEFINITIONS OF ANTHROPOMETRIC LANDMARKS AND OTHER SPECIFIC MEASUREMENT SITES

The landmarks used are basically those of Ross et al. (1978).

Acromiale - the point at the superior and external border of the scapula.

Radiale - the point at the lateral border of the head of the radius.

Stylion - the most distal point of the styloid process of the radius.

Metacarpale Radiale - the most lateral point of the head of the 2nd metacarpal.

Metacarpale Ulnare - the most medial point of the head of the 5th metacarpal.

Dactylion - the tip of the middle finger.

Ilio-cristale - the most lateral point of the iliac crest.

Ilio-spinale - the undersurface of the tip of the anterior superior iliac spine.

Trochanterion - the most superior point on the greater trochanter of the femur.

Tibiale Mediale - the most proximal point on the medial aspect of the tibia.

Tibiale Laterale - the most proximal point on the lateral aspect of the tibia.

Malleolare Externus - the most distal tip of the fibular malleolus.

Malleolare Internus - the most distal tip of the tibial malleolus.

Metatarsale Tibiale - the most medial point on the head of the 1st metatarsal.

Metatarsale Fibulare - the most lateral point on the head of the

5th metatarsal.

Akropodion - the most anterior point on the foot.

Pternion - the most posterior point on the heel of the foot when the subject is standing.

Vertex - the most superior point on the skull, in the midsagittal plane, when the head is held in the Frankfort plane position.

Tragion - notch above tragus of ear or at upper margin of zygomatic bone at that point.

Menton - chin, the most inferior border of the mandible in the median plane.

Cervicale - the tip of the spinous process of the 7th cervical vertebra.

Mesosternale - point in the centre of the body of the sternum at the level of the articulation of the 4th rib.

Thelion - breast nipple.

Xiphion - the tip of the xiphoid process of the sternum.

Gluteale - midgluteal arch, in the midline of the sacrococcygeal junction.

Axillary trunk girth - the girth of the trunk at the level of the axillary fold.

Axillary arm girth - the girth of the arm at the level of the axillary fold.

Triceps site - posterior aspect of the arm in the mid-line halfway between the acromiale and radiale.

Triceps girth - the girth of the arm at the level of the triceps site.

Biceps site - on the anterior aspect of the arm, in the mid-line at the same level as the triceps site.

Minimum arm girth - the minimum girth of the arm at a variable level usually 2 to 4 centimetres proximal to the humeral epicondyles.

Elbow girth - the girth joining the two humeral epicondyles.

Maximum forearm girth - the maximum girth of the forearm at a variable level usually 4 to 6 centimetres distal to the

humeral epicondyles.

Maximum forearm girth site - at the marked level of the maximum forearm girth on the anterior aspect of the forearm in the mid-line.

Mid-forearm girth - the girth of the arm at a level midway between the tip of the olecranon process and the stylion.

Mid-forearm site - at the marked level of the midforearm girth on the anterior aspect of the forearm in the midline.

Proximal styloid girth - the girth at the wrist proximal to the styloid processes at the minimum circumference on the forearm.

Bi-stylion girth - the girth at the wrist circumscribing the two styloid processes.

Distal styloid girth - the girth at the wrist immediately distal to the styloid processes.

Upper thigh girth - the girth of the thigh 2 centimetres distal to the natal fold of the buttock.

Mid thigh girth - the girth of the thigh at the mid point between the central point of the inguinal fold and the midpatella.

Anterior thigh site - at the marked level of the mid-thigh girth on the anterior aspect in the mid-line.

Medial thigh site - at the marked level of the mid-thigh girth on the medial aspect in the midline.

Posterior thigh site - at the marked level of the mid-thigh girth on the posterior aspect in the midline.

Maximum calf girth - the maximum girth of the leg at a variable level usually 10 to 15 cms. distal to the line of the knee joint space.

Medial calf site - at the marked level of the maximum calf girth on the medial aspect in the midline.

Mid calf girth - the girth of the leg at the level midway between the tibiale laterale and the malleolare externus.

Minimum ankle girth - the minimum girth of the leg proximal to the malleolare internus.

APPENDIX 2 - ANTHROPOMETRIC INSTRUMENTS

Skinfold calipers.

Harpenden Caliper, British Indicators Limited,
Acrewood Way,
Hatfield Road,
St Albans, Herts.,
England.

Slimguide Caliper, Creative Health Products,
5148 Saddle Ridge Road,
Michigan, 48170, U.S.A.

Anthropometric Tape.	Keuffel and Esser Whyteface steel tape. (Number 860358).
Anthropometer.	Siber-Hegner GPM anthropometer. (Martin type).
Bone Caliper.	Adapted Mitutoyo.
Widespreading Caliper.	Siber-Hegner widespreading caliper.
Weighing Apparatus.	Toledo Scale.
	Sartorius V Digital Balance.
	Mettler Precision Scale.

APPENDIX 3 - ANTHROPOMETRY

SKINFOLDS

All skinfolds are defined as the caliper distance measured 1cm distal to the skinfold which is raised at the stipulated site in the stipulated direction.

Subscapular - an oblique fold immediately infero-lateral to the inferior angle of the scapulas.

Triceps - a vertical fold at the marked triceps site.

Biceps - a vertical fold at the marked biceps site.

Maximum Forearm - a vertical fold at the marked maximum forearm site.

Mid forearm - a vertical fold at the marked mid-forearm site.

Hand (dorsum) - a vertical fold on the dorsum side of the hand above the centre of the third metacarpal.

Anterior Thigh - a vertical fold at the marked anterior thigh site.

Medial Thigh - a vertical fold at the marked medial thigh site.

Posterior Thigh - a vertical fold at the marked posterior thigh site.

Supra-patellar - a vertical fold in the midline 5cm proximal to the patellar bone.

Medial calf - a vertical fold at the marked medial calf site.

Foot (dorsum) - a vertical fold on the dorsum of the foot above the centre of the third metatarsal.

Pectoral (thelion) - an oblique fold on the line between the thelion and the anterior axillary fold 8cm below the axillary fold.

Chest (Xiphoidale) - a vertical fold in the midline on the lateral aspect of the trunk at the level of the xiphoidale.

Iliac Crest - a slightly oblique fold at the mid-axillary line 3cms above the iliac crest site.

Supraspinale - an oblique fold, running downward medially, 7cms above the marked supraspinale site on a line to the anterior axillary fold.

Abdominal - a vertical fold 1cm lateral to the umbilicus on the contralateral side to the other skinfold measures.

GIRTHS

Each girth is a perimeter measured at the stipulated marked girth wherein the tape is drawn firmly to the skin without indenting it and the measurement is made perpendicularly to the long axis of the measured part.

Arm (Axilla) - at the marked axillary girth.

Triceps - at the marked triceps girth.

Proximal Epicondylar Humerus - the girth circumscribing the two humeral epicondyles.

Elbow - at the marked elbow girth.

Maximum forearm girth - at the marked maximum forearm girth.

Mid Forearm - at the marked mid-forearm girth.

Proximal Styloid - at the marked proximal styloid girth.

Bi-styloid - at the marked bi-styloid girth.

Distal styloid - at the marked distal styloid girth.

Metacarpale - the girth of the hand encompassing the heads of metacarpals 2 to 5.

Proximal Phalanx III - the girth at the midshaft of the proximal phalanx of the third digit.

Upper thigh - at the marked upper thigh girth.

Mid thigh - at the marked mid-thigh girth.

Supra-patellar - the girth immediately proximal to the patella with the knee extended.

Mid-patellar - the girth circumscribing the centre of the patella anteriorly and the posterior knee crease posteriorly.

Infra-patellar - the girth immediately distal to the patella with the knee extended.

Maximum Calf - at the marked maximum calf girth.

Mid-Leg - at the marked mid calf girth.

Minimum Ankle - at the marked minimum ankle girth.

Bi-malleolare - the girth circumscribing the malleolares internum and externum.

Arch - the girth at the highest point of the medial longitudinal arch.

Metatarsale - the girth of the foot circumscribing the heads of metatarsales 1 to 5.

Proximal Phalanx I - the girth at the mid-shaft of the proximal phalanx of the hallux.

Forehead - the girth of the head immediately superior to the browridges.

Nasion - the girth of the head at the level of the nasion.

Mandible - the girth 1cm above the mandibular protruberance at the base of the pass alveolaris.

Suprathyroid - the girth of the neck immediately superior to the thyroid cartilage.

Infrathyroid - the girth of the neck immediately inferior to the thyroid cartilage.

DIRECT LENGTHS

Each length is the perpendicular distance between the two marked sites stipulated.

Acromiale-Radiale - the length of the arm

Radiale-Stylion - the length of the forearm

Stylion-Metacarpale III - the length of the wrist and palm

Stylion-Dactylion - the length of the wrist and the hand

Trochanterion-Tibiale - the length of the thigh

Tibiale-Malleolare Externus - the length of the leg

Malleolare-Ball of Heel - the length of the ankle

Akropodion-Pternion - the length of the foot

Vertex-Tragion - the length of the head superior to the external auditory meatus.

Vertex-Mastoid - the length of the cranium

Vertex-Menton - the length of the skull and jawbone

Inion-C7 - the length of the neck

C7-Coccyx - the length of the trunk

Total hanging length - the length of the entire body when suspended.

Supine length - the length of the entire body when supine.

BREADTHS

Each breadth is the horizontal distance between the stipulated sites.

Bi-epicondylar humerus - the arm breadth encompassing the two humeral epicondyles.

Bi-styloid - the forearm breadth encompassing the styloid processes of the radius and ulna.

Metacarpale - the hand breadth encompassing the heads of the 2nd and 5th metacarpals.

Bi-epicondylar femur - the thigh breadth encompassing the two femoral epicondyles.

Bi-condylar tibia - the leg breadth encompassing the outer aspects of the two tibial condyles.

Bi-malleolare - the ankle breadth encompassing the outer aspects

of the two malleolare.

Heel (Sub-malleolare) - the foot breadth 3cms inferior to the malleolare externum.

Metatarsale - the foot breadth encompassing the heads of the 1st and 5th metatarsals.

Bi-tragion - the head breadth encompassing the tragi of the ears.

Bi-zygomatic - the head breadth encompassing the most lateral aspects of the zygomatic arches.

Bi-acromial - the shoulder breadth encompassing the two marked acromiale sites.

Mesosternale - the chest breadth at the level of the marked mesosternale site.

Xiphoidale - the chest breadth at the level of the naked xiphoidale site.

Bi-iliocristale - the hip breadth encompassing the marked ilio-cristale sites.

Bi-trochanteric - the hip and thigh breadth encompassing the marked trochanterion sites.

DEPTHS

Each depth was measured at the stipulated site at right angles to the long axis of the body in a saggital plane.

Metacarpale III - the hand depth at the head of the third metacarpal.

Metatarsale III - the foot depth at the head of the third metatarsal.

A-P Chest (Mesosternale) - the chest depth at the marked mesosternale site.

A-P Chest (Xiphoidale) - the chest depth at the marked xiphoidale site.

Buttock - the depth of the pelvis at the pubic symphysis.

Inion-glabella - the depth of the head.

APPENDIX 4 - OSTEOMETRIC MEASURES

The majority of these measures follow the methods of Martin and Saller (1959).

Maximum humerus length - the distance between the proximal point of the caput humeri and the distal point of the capitulum radialis humeri; anthropometer parallel to humerus shaft.

Mid humerus girth - the girth of the shaft of the humerus at the point corresponding to the mid-arm girth (as determined by the reference distance from the lateral epicondyle).

Proximal epicondylar humerus girth - the girth of the shaft of the humerus at the point corresponding to the minimum arm girth (as determined by the reference distance from the lateral epicondyle).

Bi-epicondylar humerus girth - the girth of the humerus encorporating the two humeral epicondyles.

Bi-epicondylar humerus breadth- the greatest distance between the epicondyles of the humerus.

Ulna length - The distance between the olecranon and the styloid process. Ulna horizontal with olecranon downwards; anthropometer parallel to shaft.

Maximum forearm ulnar girth - the girth of the shaft of the ulna at the point corresponding to the maximum forearm girth (as determined by the reference distance from the tip of the olecranon process).

Mid ulnar girth - the girth of the shaft of the ulna at the point corresponding to the mid-forearm girth (as determined by the reference distance from the tip of the olecranon process).

Radius length - the distance between the most proximal part of the head of the radius and the most distal part of the styloid proocess of the radius. Radius horizontal; anthropometer parallel to shaft.

Maximum forearm radial girth - the girth of the shaft of the radius at the point corresponding to the maximum-forearm girth (as determined by the reference distance from the tip of the olecranon process, site marked when radius and ulna are in juxtaposition).

Mid radial girth - the girth of the shaft of the radius at the point corresponding to the mid-forearm girth (as determined

by the reference distance from the tip of the olecranon process, site marked when radius and ulna are in juxtaposition).

Maximum femur length - the greatest distance between the proximal point of the caput femoris and the most distal point of either the condylus medialis or lateralis. Femur horizontal, the facies patellae upwards and the caput femoris away from the measurer; anthropometer parallel to the shaft.

Trochanterion-condyle length - the distance between the proximal edge of the trochanter majus and the distal point of the condylus lateralis. Femur horizontal, the facies patellae upwards and the caput femoris away from the measurer; anthropometer parallel to the shaft.

Upper thigh femur girth - the girth of the shaft of the femur at the point corresponding to the upper thigh girth (as determined by the reference distance from the medial femoral epicondyle).

Mid thigh femur girth - the girth of the shaft of the femur at the point corresponding to the mid thigh girth (as determined by the reference distance from the medial femoral epicondyle).

Bi-epicondylar femur girth - the girth of the femur incorporating the two femoral epicondyles.

Bi-epicondylar femur breadth - the greatest distance between the epicondyles of the femur.

Maximum tibia length - the distance between the most proximal point of the tibial intercondylar eminence and the most distal point of the sphyrion tibiale, anthropometer parallel to the tibial shaft.

Tibiale mediale-malleolare internus length - the distance between the proximal medial point of the medial tibial condyle and the most medial point of the tibial malleolus.

Maximum calf tibial girth - the girth of the shaft of the tibia at the point corresponding to the maximum calf girth (as determined by the reference distance from the tibiale laterale).

Mid calf tibial girth - the girth of the shaft of the tibia at the point corresponding to the mid calf girth (as determined by the reference distance from the tibiale laterale).

Maximum fibula length - the distance between the most proximal point on the apex of the fibula and the most distal point on

the sphyrion fibulare, anthropometer parallel to the fibular shaft.

Head of fibula - malleolare externus length - the distance from the most lateral point on the head of the fibula to the most lateral point of the fibular malleolus.

Maximum calf fibular girth - the girth of the shaft of the fibula at the point corresponding to the maximum calf girth (as determined by the reference distance from the tibiale laterale).

Mid calf fibular girth - the girth of the shaft of the fibula at the point corresponding to the mid calf girth (as determined by the reference distance from the tibiale laterale).

APPENDIX 5 - RAW DATA FOR SUBJECTS 1 TO 6

VARIABLE LABELS

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SUBNUM,SUBJECT NUMBER/
SEX,SEX/
DOB,DATE OF BIRTH/
DODEM,DATE OF DEMISE/
AGEATDEM,AGE AT DEMISE/
DOANTHR,DATE OF ANTHROPOMETRY/
DODISS,DATE OF DISSECTION/

SFHSUBL,SKINFOLD HARPENDON SUBSCAPULAR LEFT/
SFHTRL,SKINFOLD HARPENDON TRICEPS LEFT/
SFHBIL,SKINFOLD HARPENDON BICEPS LEFT/
SFHMXFL,SKINFOLD HARPENDON MAXIMUM FOREARM LEFT/
SFHMDFL,SKINFOLD HARPENDON MID-FOREARM LEFT/
SFHHL,SKINFOLD HARPENDON HAND LEFT/
SFHANTTL,SKINFOLD HARPENDON ANTERIOR THIGH LEFT/
SFHMEDTL,SKINFOLD HARPENDON MEDIAL THIGH LEFT/
SFHPOSTL,SKINFOLD HARPENDON POSTERIOR THIGH LEFT/
SFHSUPPL,SKINFOLD HARPENDON SUPRA-PATELLAR LEFT/
SFHMEDCL,SKINFOLD HARPENDON MEDIAL CALF LEFT/
SFHFL,SKINFOLD HARPENDON FOOT LEFT/

SFHSUBR,SKINFOLD HARPENDON SUBSCAPULAR RIGHT/
SFHTRR,SKINFOLD HARPENDON TRICEPS RIGHT/
SFHBIR,SKINFOLD HARPENDON BICEPS RIGHT/
SFHMXFR,SKINFOLD HARPENDON MAXIMUM FOREARM RIGHT/
SFHMDFR,SKINFOLD HARPENDON MID-FOREARM RIGHT/
SFHHR,SKINFOLD HARPENDON HAND RIGHT/
SFHANTTR,SKINFOLD HARPENDON ANTERIOR THIGH RIGHT/
SFHMEDTR,SKINFOLD HARPENDON MEDIAL THIGH RIGHT/
SFHPOSTR,SKINFOLD HARPENDON POSTERIOR THIGH RIGHT/
SFHSUPPR,SKINFOLD HARPENDON SUPRA-PATELLAR RIGHT/
SFHMEDCR,SKINFOLD HARPENDON MEDIAL CALF RIGHT/
SFHFR,SKINFOLD HARPENDON FOOT RIGHT/

SFSSUBL,SKINFOLD SLIMGUIDE SUBSCAPULAR LEFT/
SFSTRL,SKINFOLD SLIMGUIDE TRICEPS LEFT/
SFSBIL,SKINFOLD SLIMGUIDE BICEPS LEFT/
SFSMXFL,SKINFOLD SLIMGUIDE MAXIMUM FOREARM LEFT/
SFSMDFL,SKINFOLD SLIMGUIDE MID-FOREARM LEFT/
SFSANTTL,SKINFOLD SLIMGUIDE ANTERIOR THIGH LEFT/
SFSMEDTL,SKINFOLD SLIMGUIDE MEDIAL THIGH LEFT/
SFSPOSTL,SKINFOLD SLIMGUIDE POSTERIOR THIGH LEFT/
SFSSUPPL,SKINFOLD SLIMGUIDE SUPRA-PATELLAR LEFT/
SFSMEDCL,SKINFOLD SLIMGUIDE MEDIAL CALF LEFT/
SFSFL,SKINFOLD SLIMGUIDE FOOT LEFT/
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SFSHL,SKINFOLD SLIMGUIDE HAND LEFT/

SFSSUBR,SKINFOLD SLIMGUIDE SUBSCAPULAR RIGHT/
SFSTRR,SKINFOLD SLIMGUIDE TRICEPS RIGHT/
SFSBIR,SKINFOLD SLIMGUIDE BICEPS RIGHT/
SFSMXFR,SKINFOLD SLIMGUIDE MAXIMUM FOREARM RIGHT/
SFSMDFR,SKINFOLD SLIMGUIDE MID-FOREARM RIGHT/
SFSANTTR,SKINFOLD SLIMGUIDE ANTERIOR THIGH RIGHT/
SFSMEDTR,SKINFOLD SLIMGUIDE MEDIAL THIGH RIGHT/
SFSPOSTR,SKINFOLD SLIMGUIDE POSTERIOR THIGH RIGHT/
SFSSUPPR,SKINFOLD SLIMGUIDE SUPRA-PATELLAR RIGHT/
SFSMEDCR,SKINFOLD SLIMGUIDE MEDIAL CALF RIGHT/
SFSFR,SKINFOLD SLIMGUIDE FOOT RIGHT/
SFSHR,SKINFOLD SLIMGUIDE HAND RIGHT/


GAXARML,GIRTH AXILLARY ARM LEFT/
GTRL,GIRTH TRICEPS LEFT/
GELL,GIRTH ELBOW LEFT/
GMXFL,GIRTH MAXIMUM FOREARM LEFT/
GMDFL,GIRTH MID-FOREARM LEFT/
GPRSTYL,GIRTH PROXIMAL STYLOID LEFT/
GBISTYL,GIRTH BI-STYLOID LEFT/
GDISTYL,GIRTH DISTAL STYLOID LEFT/
GMETACL,GIRTH METACARPAL LEFT/
GPHAL3L,GIRTH PHALANX THREE LEFT/
GUPTHL,GIRTH UPPER THIGH LEFT/
GMDTHL,GIRTH MID-THIGH LEFT/
GSUPPATL,GIRTH SUPRA-PATELLAR LEFT/
GMDPATL,GIRTH MID-PATELLAR LEFT/
GINFPATL,GIRTH INFRA-PATELLAR LEFT/
GMXCAL,GIRTH MAXIMUM CALF LEFT/
GMNANKL,GIRTH MINIMUM ANKLE LEFT/
GBIMALL,GIRTH BI-MALLEOLAR LEFT/
GMETATL,GIRTH METATARSAL LEFT/
GPHAL1L,GIRTH HALLUX LEFT/
GARCL,GIRTH ARCH LEFT/
GMDLEGL,GIRTH MID-CALF LEFT/
GMNARML,GIRTH MINIMUM ARM LEFT/

GAXARMR,GIRTH AXILLARY ARM RIGHT/
GTRR,GIRTH TRICEPS RIGHT/
GELR,GIRTH ELBOW RIGHT/
GMXFR,GIRTH MAXIMUM FOREARM RIGHT/
GMDFR,GIRTH MID-FOREARM RIGHT/
GPRSTYR,GIRTH PROXIMAL STYLOID RIGHT/
GBISTYR,GIRTH BI-STYLOID RIGHT/
GDISTYR,GIRTH DISTAL STYLOID RIGHT/
GMETACR,GIRTH METACARPAL RIGHT/
GPHAL3R,GIRTH PHALANX THREE RIGHT/
GUPTHR,GIRTH UPPER THIGH RIGHT/
GMDTHR,GIRTH MID-THIGH RIGHT/
GSUPPATR,GIRTH SUPRA-PATELLAR RIGHT/
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GMDPATR,GIRTH MID-PATELLAR RIGHT/
GINFPATR,GIRTH INFRA-PATELLAR RIGHT/
GMXCAR,GIRTH MAXIMUM CALF RIGHT/
GMNANKR,GIRTH MINIMUM ANKLE RIGHT/
GBIMALR,GIRTH BI-MALLEOLAR RIGHT/
GMETATR,GIRTH METATARSAL RIGHT/
GPHAL1R,GIRTH HALLUX RIGHT/
GARCR,GIRTH ARCH RIGHT/
GMDLEGR,GIRTH MID-CALF RIGHT/
GMNARMR,GIRTH MINIMUM ANKLE RIGHT/


LACRADL,LENGTH ACROMIALE-RADIALE LEFT/
LRADSTYL,LENGTH RADIALE-STYLION LEFT/
LSTYMETL,LENGTH STYLION-METACARPALE LEFT/
LSTYDACL,LENGTH STYLION-DACTYLION LEFT/
LTROTIBL,LENGTH TROCHANTERION-TIBIALE LEFT/
LTIBMALL,LENGTH TIBIALE-MALLEOLARE LEFT/
LMALBALL,LENGTH MALLEOLARE-BALL OF HEEL LEFT/
LAKPTEL,LENGTH AKROPODION-PTERNION LEFT/

LACRADR,LENGTH ACROMIALE-RADIALE RIGHT/
LRADSTYR,LENGTH RADIALE-STYLION RIGHT/
LSTYMETR,LENGTH STYLION-METACARPALE RIGHT/
LSTYDACR,LENGTH STYLION-DACTYLION RIGHT/
LTROTIBR,LENGTH TROCHANTERION-TIBIALE RIGHT/
LTIBMALR,LENGTH TIBIALE-MALLEOLARE RIGHT/
LMALBALR,LENGTH MALLEOLARE-BALL OF HEEL RIGHT/
LAKPTER,LENGTH AKROPODION-PTERNION RIGHT/


BEPIHUL,BREADTH EPI-CONDYLAR HUMERUS LEFT/
BBISTYL,BREADTH BI-STYLOID LEFT/
BEPIFEL,BREADTH EPI-CONDYLAR FEMUR LEFT/
BCONTIL,BREADTH CONDYLAR TIBIA LEFT/
BBIMALL,BREADTH BI-MALLEOLAR LEFT/
BHEELL,BREADTH HEEL LEFT/
BMETATL,BREADTH METATARSAL LEFT/
BMETACL,BREADTH METACARPAL LEFT/

BEPIHUR,BREADTH EPI-CONDYLAR HUMERUS RIGHT/
BBISTYR,BREADTH BI-STYLOID RIGHT/
BEPIFER,BREADTH EPI-CONDYLAR FEMUR RIGHT/
BCONTIR,BREADTH CONDYLAR TIBIA RIGHT/
BBIMALR,BREADTH BI-MALLEOLAR RIGHT/
BHEELR,BREADTH HEEL RIGHT/
BMETATR,BREADTH METATARSAL RIGHT/
BMETACR,BREADTH METACARPAL RIGHT/


DMETACL,DEPTH METACARPAL LEFT/
DMETATL,DEPTH METATARSAL LEFT/
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DMETACR,DEPTH METACARPAL RIGHT/
DMETATR,DEPTH METATARSAL RIGHT/


TSFHAXL,TRUNK SKINFOLD HARPENDON AXILLA LEFT/
TSFHXIL,TRUNK SKINFOLD HARPENDON XIPHOID LEFT/
TSFHICL,TRUNK SKINFOLD HARPENDON ILIAC CREST LEFT/
TSFHSSL,TRUNK SKINFOLD HARPENDON SUPRA-SPINALE LEFT/
TSFHABL,TRUNK SKINFOLD HARPENDON ABDOMINAL LEFT/

TSFHAXR,TRUNK SKINFOLD HARPENDON AXILLA RIGHT/
TSFHXIR,TRUNK SKINFOLD HARPENDON XIPHOID RIGHT/
TSFHICR,TRUNK SKINFOLD HARPENDON ILIAC CREST RIGHT/
TSFHSSR,TRUNK SKINFOLD HARPENDON SUPRA-SPINALE RIGHT/
TSFHABR,TRUNK SKINFOLD HARPENDON ABDOMINAL RIGHT/

TSFSAXL,TRUNK SKINFOLD SLIMGUIDE AXILLA LEFT/
TSFSXIL,TRUNK SKINFOLD SLIMGUIDE XIPHOID LEFT/
TSFSICL,TRUNK SKINFOLD SLIMGUIDE ILIAC CREST LEFT/
TSFSSSL,TRUNK SKINFOLD SLIMGUIDE SUP.SPINALE LEFT/
TSFSABL,TRUNK SKINFOLD SLIMGUIDE ABDOMINAL LEFT/

TGAX,TRUNK GIRTH AXILLA/
TGMESOST,TRUNK GIRTH MESOSTERNALE/
TGTHBF,TRUNK GIRTH THELION OR BREASTFOLD/
TGXIPH,TRUNK GIRTH XIPHOIDALE/
TGWAI,TRUNK GIRTH WAIST/
TGHIP,TRUNK GIRTH HIP/

TLC7CO,TRUNK LENGTH CERVICALE-COCCYX/

TBBIAC,TRUNK BREADTH BI-ACROMIAL/
TBMESOST,TRUNK BREADTH MESOSTERNALE/
TBXIPH,TRUNK BREADTH XIPHOIDALE/
TBBIILCR,TRUNK BREADTH BI-ILIOCRISTAL/
TBBITROC,TRUNK BREADTH BI-TROCHANTERIC/

LTOTHANG,LENGTH TOTAL HANGING SUSPENDED/

DAPCHMES,DEPTH ANT.-POST. CHEST MESOSTERNALE/
DAPCHXI,DEPTH ANT.-POST. CHEST XIPHOIDALE/
DBUTT,DEPTH BUTTOCK/

HGFHD,HEAD GIRTH FOREHEAD/
HGNAS,HEAD GIRTH NASION/
HGMAND,HEAD GIRTH MANDIBLE/
NGSUPTHY,NECK GIRTH SUPRA-THYROID/
NGINFTHY,NECK GIRTH INFRA-THYROID/
HLVERTRA,HEAD LENGTH VERTEX-TRAGION
HLVERMEN,HEAD LENGTH VERTEX-MENTON/
HLVERMAS,HEAD LENGTH VERTEX-MASTOID PROCESS/
HBBITRA,HEAD BREADTH BI-TRAGION/
HBBIZY,HEAD BREADTH BI-ZYGOMATIC/
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HDINGLAB,HEAD DEPTH INION-GLABELLA/
HLINC7,HEAD LENGTH INION-CERVICALE/

LTOTSUS,LENGTH TOTAL HANGING SUSPENDED/
LTOTSUP,LENGTH TOTAL SUPINE/

"U-W" WILL BE USED TO INDICATE
"UNDER WATER".

WATBBWW,WEIGHT TOTAL BODY BEFORE U-W WEIGHING/
WATBAWW,WEIGHT TOTAL BODY AFTER U-W WEIGHING/
WALUNH2O,WEIGHT OF WATER IN LUNGS/
WWCADCF,U-W WEIGHT CADAVER CROSS AND FRAME/
WWCF,U-W WEIGHT CROSS AND FRAME/
WWCAD,U-W WEIGHT CADAVER/
WATBBDI,WEIGHT TOTAL BODY BEFORE DISSECTION/

WABATOTL,WEIGHT IN AIR TOTAL ARM LEFT/
WWBATOTL,WEIGHT U-W TOTAL ARM LEFT/
WAVATOTL,WEIGHT IN AIR TOTAL FOREARM LEFT/
WWVATOTL,WEIGHT U-W TOTAL FOREARM LEFT/
WAHATOTL,WEIGHT IN AIR TOTAL HAND LEFT/
WWHATOTL,WEIGHT U-W TOTAL HAND LEFT/
WADTOTL,WEIGHT IN AIR TOTAL THIGH LEFT/
WWDTOTL,WEIGHT U-W TOTAL THIGH LEFT/
WAKTOTL,WEIGHT IN AIR TOTAL LEG LEFT/
WWKTOTL,WEIGHT U-W TOTAL LEG LEFT/
WAVTOTL,WEIGHT IN AIR TOTAL FOOT LEFT/
WWVTOTL,WEIGHT U-W TOTAL FOOT LEFT/

WABATOTR,WEIGHT IN AIR TOTAL ARM RIGHT/
WWBATOTR,WEIGHT U-W TOTAL ARM RIGHT/
WAVATOTR,WEIGHT IN AIR TOTAL FOREARM RIGHT/
WWVATOTR,WEIGHT U-W TOTAL FOREARM RIGHT/
WAHATOTR,WEIGHT IN AIR TOTAL HAND RIGHT/
WWHATOTR,WEIGHT U-W TOTAL HAND RIGHT/
WADTOTR,WEIGHT IN AIR TOTAL THIGH RIGHT/
WWDTOTR,WEIGHT U-W TOTAL THIGH RIGHT/
WAKTOTR,WEIGHT IN AIR TOTAL LEG RIGHT/
WWKTOTR,WEIGHT U-W TOTAL LEG RIGHT/
WAVTOTR,WEIGHT IN AIR TOTAL FOOT RIGHT/
WWVTOTR,WEIGHT U-W TOTAL FOOT RIGHT/

WAHEAD,WEIGHT IN AIR HEAD/
WWHEAD,WEIGHT U-W HEAD/
WATR,WEIGHT IN AIR TRUNK/
WWTR&C&F,WEIGHT U-W TRUNK & CROSS & FRAME/
WWC&F,WEIGHT U-W CROSS & FRAME/
WWTR,WEIGHT U-W TRUNK/

WAFLBUPS,WEIGHT FLUID & BUCKET POST SEGMENTATION/
WABUPS,WEIGHT BUCKET POST SEGMENTATION/
WAFLPS,WEIGHT FLUID POST SEGMENTATION/
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LBGBAAXL,LEAN BODY GIRTH ARM AXILLA LEFT/
LBGBATRL,LEAN BODY GIRTH ARM TRICEPS LEFT/
LBGBAEPL,LEAN BODY GIRTH ARM EPICOND. LEFT/
LBBBAEPL,LEAN BODY BREADTH ARM EPICOND. LEFT/
LBGBAPRL,LEAN BODY GIRTH ARM PROX.EPICOND. LEFT/

LBGBAAXR,LEAN BODY GIRTH ARM AXILLA RIGHT/
LBGBATRR,LEAN BODY GIRTH ARM TRICEPS RIGHT/
LBGBAEPR,LEAN BODY GIRTH ARM EPICOND. RIGHT/
LBBBAEPR,LEAN BODY BREADTH ARM EPICOND. RIGHT/
LBGBAPRR,LEAN BODY GIRTH ARM PROX.EPICOND. RIGHT/

LBGVAMXL,LEAN BODY GIRTH FOREARM MAXIMUM LEFT/
LBGVAMDL,LEAN BODY GIRTH FOREARM MIDDLE LEFT/
LBGVAPRL,LEAN BODY GIRTH FOREARM PROX.STYL. LEFT/
LBGVABIL,LEAN BODY GIRTH FOREARM BI-STYLION LEFT/
LBBVABIL,LEAN BODY BREADTH BI-STYLION LEFT/

LBGVAMXR,LEAN BODY GIRTH FOREARM MAXIMUM RIGHT/
LBGVAMDR,LEAN BODY GIRTH FOREARM MIDDLE RIGHT/
LBGVAPRR,LEAN BODY GIRTH FOREARM PROX.STYL. RIGHT/
LBGVABIR,LEAN BODY GIRTH FOREARM BI-STYLION RIGHT/
LBBVABIR,LEAN BODY BREADTH BI-STYLION RIGHT/

LBGHMETL,LEAN BODY GIRTH HAND METACARPAL LEFT/
LBGHPH3L,LEAN BODY GIRTH HAND PHALANX 3 LEFT/
LBBHMETL,LEAN BODY BREADTH HAND METACARPAL LEFT/
LBDHMETL,LEAN BODY DEPTH HAND METACARPAL LEFT/

LBGHMETR,LEAN BODY GIRTH HAND METACARPAL RIGHT/
LBGHPH3R,LEAN BODY GIRTH HAND PHALANX 3 RIGHT/
LBBHMETR,LEAN BODY BREADTH HAND METACARPAL RIGHT/
LBDHMETR,LEAN BODY DEPTH HAND METACARPAL RIGHT/

LBGDUPL,LEAN BODY GIRTH THIGH UPPER LEFT/
LBGDMDL,LEAN BODY GIRTH THIGH MIDDLE LEFT/
LBGDSUPL,LEAN BODY GIRTH THIGH SUP.-PATELLAR LEFT/
LBGDEPIL,LEAN BODY GIRTH THIGH EPICOND. LEFT/
LBBDEPIL,LEAN BODY BREADTH THIGH EPICOND.LEFT/

LBGDUPR,LEAN BODY GIRTH THIGH UPPER RIGHT/
LBGDMDR,LEAN BODY GIRTH THIGH MIDDLE RIGHT/
LBGDSUPR,LEAN BODY GIRTH THIGH SUP.-PATELLAR RIGHT/
LBGDEPIR,LEAN BODY GIRTH THIGH EPICOND. RIGHT/
LBBDEPIR,LEAN BODY BREADTH THIGH EPICOND.RIGHT/

LBGKIPL,LEAN BODY GIRTH LEG INF.-PATELLAR LEFT/
LBGKMXL,LEAN BODY GIRTH LEG MAXIMUM LEFT/
LBGKMDL,LEAN BODY GIRTH LEG MIDDLE LEFT/
LBGKMNL,LEAN BODY GIRTH LEG MINIMUM LEFT/
LBBKCONL,LEAN BODY BREADTH LEG BI-COND. LEFT/
LBBKMALL,LEAN BODY BREADTH LEG BI-MALL. LEFT/

LBGKIPR,LEAN BODY GIRTH LEG INF.-PATELLAR RIGHT/
LBGKMXR,LEAN BODY GIRTH LEG MAXIMUM RIGHT/
LBGKMDR,LEAN BODY GIRTH LEG MIDDLE RIGHT/
LBGKMNR,LEAN BODY GIRTH LEG MINIMUM RIGHT/
LBBKCONR,LEAN BODY BREADTH LEG BI-COND. RIGHT/
LBBKMALR,LEAN BODY BREADTH LEG BI-MALL. RIGHT/

LBGVMETL,LEAN BODY GIRTH FOOT METATARSAL LEFT/
LBGVHALL,LEAN BODY GIRTH FOOT HALLUX LEFT/
LBGVARCL,LEAN BODY GIRTH FOOT ARCH LEFT/
LBBVMETL,LEAN BODY BREADTH FOOT METATARSAL LEFT/
LBDVMETL,LEAN BODY DEPTH FOOT METATARSAL 3 LEFT/

LBGVMETR,LEAN BODY GIRTH FOOT METATARSAL RIGHT/
LBGVHALR,LEAN BODY GIRTH FOOT HALLUX RIGHT/
LBGVARCR,LEAN BODY GIRTH FOOT ARCH RIGHT/
LBBVMETR,LEAN BODY BREADTH FOOT METATARSAL RIGHT/
LBDVMETR,LEAN BODY DEPTH FOOT METATARSAL 3 RIGHT/

WWGA&WT,WEIGHT U-W GAUZE AND BRASS WEIGHT/

WABASL,WEIGHT IN AIR ARM SKIN LEFT/
WWBASL,WEIGHT U-W ARM SKIN LEFT/
WABAFL,WEIGHT IN AIR ARM FAT LEFT/
WWBAFL,WEIGHT U-W ARM FAT LEFT/
WABAML,WEIGHT IN AIR ARM MUSCLE LEFT/
WWBAML,WEIGHT U-W ARM MUSCLE LEFT/
WABABL,WEIGHT IN AIR ARM BONE LEFT/
WWBABL,WEIGHT U-W ARM BONE LEFT/

WABASR,WEIGHT IN AIR ARM SKIN RIGHT/
WWBASR,WEIGHT U-W ARM SKIN RIGHT/
WABAFR,WEIGHT IN AIR ARM FAT RIGHT/
WWBAFR,WEIGHT U-W ARM FAT RIGHT/
WABAMR,WEIGHT IN AIR ARM MUSCLE RIGHT/
WWBAMR,WEIGHT U-W ARM MUSCLE RIGHT/
WABABR,WEIGHT IN AIR ARM BONE RIGHT/
WWBABR,WEIGHT U-W ARM BONE RIGHT/

WAVASL,WEIGHT IN AIR FOREARM SKIN LEFT/
WWVASL,WEIGHT U-W FOREARM SKIN LEFT/
WAVAFL,WEIGHT IN AIR FOREARM FAT LEFT/
WWVAFL,WEIGHT U-W FOREARM FAT LEFT/
WAVAML,WEIGHT IN AIR FOREARM MUSCLE LEFT/
WWVAML,WEIGHT U-W FOREARM MUSCLE LEFT/
WAVABRL,WEIGHT IN AIR FOREARM BONE RADIUS LEFT/
WWVABRL,WEIGHT U-W FOREARM BONE RADIUS LEFT/
WAVABUL,WEIGHT IN AIR FOREARM BONE ULNA LEFT/
WWVABUL,WEIGHT U-W FOREARM BONE ULNA LEFT/

WAVASR,WEIGHT IN AIR FOREARM SKIN RIGHT/
WWVASR,WEIGHT U-W FOREARM SKIN RIGHT/

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WAVAFR,WEIGHT IN AIR FOREARM FAT RIGHT/
WWVAFR,WEIGHT U-W FOREARM FAT RIGHT/
WAVAMR,WEIGHT IN AIR FOREARM MUSCLE RIGHT/
WWVAMR,WEIGHT U-W FOREARM MUSCLE RIGHT/
WAVABRR,WEIGHT IN AIR FOREARM BONE RADIUS RIGHT/
WWVABRR,WEIGHT U-W FOREARM BONE RADIUS RIGHT/
WAVABUR,WEIGHT IN AIR FOREARM BONE ULNA RIGHT/
WWVABUR,WEIGHT U-W FOREARM BONE ULNA RIGHT/

WAHSL,WEIGHT IN AIR HAND SKIN LEFT/
WWHSL,WEIGHT U-W HAND SKIN LEFT/
WAHFL,WEIGHT IN AIR HAND FAT LEFT/
WWHFL,WEIGHT U-W HAND FAT LEFT/
WAHML,WEIGHT IN AIR HAND MUSCLE LEFT/
WWHML,WEIGHT U-W HAND MUSCLE LEFT/
WAHBL,WEIGHT IN AIR HAND BONE LEFT/
WWHBL,WEIGHT U-W HAND BONE LEFT/

WAHSR,WEIGHT IN AIR HAND SKIN RIGHT/
WWHSR,WEIGHT U-W HAND SKIN RIGHT/
WAHFR,WEIGHT IN AIR HAND FAT RIGHT/
WWHFR,WEIGHT U-W HAND FAT RIGHT/
WAHMR,WEIGHT IN AIR HAND MUSCLE RIGHT/
WWHMR,WEIGHT U-W HAND MUSCLE RIGHT/
WAHBR,WEIGHT IN AIR HAND BONE RIGHT/
WWHBR,WEIGHT U-W HAND BONE RIGHT/

WADSL,WEIGHT IN AIR THIGH SKIN LEFT/
WWDSL,WEIGHT U-W THIGH SKIN LEFT/
WADFL,WEIGHT IN AIR THIGH FAT LEFT/
WWDFL,WEIGHT U-W THIGH FAT LEFT/
WADML,WEIGHT IN AIR THIGH MUSCLE LEFT/
WWDML,WEIGHT U-W THIGH MUSCLE LEFT/
WADBFL,WEIGHT IN AIR THIGH BONE FEMUR LEFT/
WWDBFL,WEIGHT U-W THIGH BONE FEMUR LEFT/
WADBPL,WEIGHT IN AIR THIGH BONE PATELLA LEFT/
WWDBPL,WEIGHT U-W THIGH BONE PATELLA LEFT/

WADSR,WEIGHT IN AIR THIGH SKIN RIGHT/
WWDSR,WEIGHT U-W THIGH SKIN RIGHT/
WADFR,WEIGHT IN AIR THIGH FAT RIGHT/
WWDFR,WEIGHT U-W THIGH FAT RIGHT/
WADMR,WEIGHT IN AIR THIGH MUSCLE RIGHT/
WWDMR,WEIGHT U-W THIGH MUSCLE RIGHT/
WADBFR,WEIGHT IN AIR THIGH BONE FEMUR RIGHT/
WWDBFR,WEIGHT U-W THIGH BONE FEMUR RIGHT/
WADBPR,WEIGHT IN AIR THIGH BONE PATELLA RIGHT/
WWDBPR,WEIGHT U-W THIGH BONE PATELLA RIGHT/

WAKSL,WEIGHT IN AIR LEG SKIN LEFT/
WWKSL,WEIGHT U-W LEG SKIN LEFT/
WAKFL,WEIGHT IN AIR LEG FAT LEFT/
WWKFL,WEIGHT U-W LEG FAT LEFT/
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WAKML,WEIGHT IN AIR LEG MUSCLE LEFT/
WWKML,WEIGHT U-W LEG MUSCLE LEFT/
WAKBTL,WEIGHT IN AIR LEG BONE TIBIA LEFT/
WWKBTL,WEIGHT U-W LEG BONE TIBIA LEFT/
WAKBFL,WEIGHT IN AIR LEG BONE FIBULA LEFT/
WWKBFL,WEIGHT U-W LEG BONE FIBULA LEFT/

WAKSR,WEIGHT IN AIR LEG SKIN RIGHT/
WWKSR,WEIGHT U-W LEG SKIN RIGHT/
WAKFR,WEIGHT IN AIR LEG FAT RIGHT/
WWKFR,WEIGHT U-W LEG FAT RIGHT/
WAKMR,WEIGHT IN AIR LEG MUSCLE RIGHT/
WWKMR,WEIGHT U-W LEG MUSCLE RIGHT/
WAKBTR,WEIGHT IN AIR LEG BONE TIBIA RIGHT/
WWKBTR,WEIGHT U-W LEG BONE TIBIA RIGHT/
WAKBFR,WEIGHT IN AIR LEG BONE FIBULA RIGHT/
WWKBFR,WEIGHT U-W LEG BONE FIBULA RIGHT/

WAVSL,WEIGHT IN AIR FOOT SKIN LEFT/
WWVSL,WEIGHT U-W FOOT SKIN LEFT/
WAVFL,WEIGHT IN AIR FOOT FAT LEFT/
WWVFL,WEIGHT U-W FOOT FAT LEFT/
WAVML,WEIGHT IN AIR FOOT MUSCLE LEFT/
WWVML,WEIGHT U-W FOOT MUSCLE LEFT/
WAVBL,WEIGHT IN AIR FOOT BONE LEFT/
WWVBL,WEIGHT U-W FOOT BONE LEFT/

WAVSR,WEIGHT IN AIR FOOT SKIN RIGHT/
WWVSR,WEIGHT U-W FOOT SKIN RIGHT/
WAVFR,WEIGHT IN AIR FOOT FAT RIGHT/
WWVFR,WEIGHT U-W FOOT FAT RIGHT/
WAVMR,WEIGHT IN AIR FOOT MUSCLE RIGHT/
WWVMR,WEIGHT U-W FOOT MUSCLE RIGHT/
WAVBR,WEIGHT IN AIR FOOT BONE RIGHT/
WWVBR,WEIGHT U-W FOOT BONE RIGHT/

WAFLBUPF,WEIGHT FLUID & BUCKET POST FRACTIONATION/
WABUPF,WEIGHT BUCKET POST FRACTIONATION/
WAFLPF,WEIGHT FLUID POST FRACTIONATION

OGVASTYL,OSTEO GIRTH FOREARM STYLION LEFT/
OGVAMXL,OSTEO GIRTH FOREARM MAXIMUM LEFT/
OGVAMDL,OSTEO GIRTH FOREARM MIDDLE LEFT/
OGVAMNL,OSTEO GIRTH FOREARM MINIMUM LEFT/
OBVASTYL,OSTEO BREADTH FOREARM STYLION LEFT/

OGVASTYR,OSTEO GIRTH FOREARM STYLION RIGHT/
OGVAMXR,OSTEO GIRTH FOREARM MAXIMUM RIGHT/
OGVAMDR,OSTEO GIRTH FOREARM MIDDLE RIGHT/
OGVAMNR,OSTEO GIRTH FOREARM MINIMUM RIGHT/
OBVASTYR,OSTEO BREADTH FOREARM STYLION RIGHT/

OGKMNL,OSTEO GIRTH LEG MINIMUM LEFT/
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OGKMXL,OSTEO GIRTH LEG MAXIMUM LEFT/
OGKMDL,OSTEO GIRTH LEG MIDDLE LEFT/
OGKMALL,OSTEO GIRTH LEG MALLEOLAR LEFT/
OBKMALL,OSTEO BREADTH LEG MALLEOLAR LEFT/
OLKTIEML,OSTEO LENGTH LEG TIBIALE-EXT.MALL. LEFT/

OGKMNR,OSTEO GIRTH LEG MINIMUM RIGHT/
OGKMXR,OSTEO GIRTH LEG MAXIMUM RIGHT/
OGKMDR,OSTEO GIRTH LEG MIDDLE RIGHT/
OGKMALR,OSTEO GIRTH LEG MALLEOLAR RIGHT/
OBKMALR,OSTEO BREADTH LEG MALLEOLAR RIGHT/
OLKTIEMR,OSTEO LENGTH LEG TIBIALE-EXT.MALL. RIGHT/

RLAXMEHL,REFERENCE LENGTH AX-MED.EPIHUM LT/
RLTRLEHL,REFERENCE LENGTH TRI-LAT.EPIHUM LT/
RLMNLEHL,REFERENCE LENGTH MIN-LAT.EPIHUM LT/
RLOMXVAL,REFERENCE LENGTH OL-MAX.F.ARM LT/
RLOMDVAL,REFERENCE LENGTH OL-MID.F.ARM LT/
RLPWSTYL,REFERENCE LENGTH PROX. TO STY LT/
RLUDTRL,REFERENCE LENGTH UP.TH-TROCH LT/
RLMDDTRL,REFERENCE LENGTH MID.TH-TROCH LT/
RLMXKTIL,REFERENCE LENGTH MAX.LEG-TIB.LAT. LT/
RLMDKTIL,REFERENCE LENGTH MID.LEG-TIB.LAT. LT/
RLMNKMAL,REFERENCE LENGTH MIN.ANK-MAL.LAT. LT/

RLAXMEHR,REFERENCE LENGTH AX-MED.EPIHUM RT/
RLTRLEHR,REFERENCE LENGTH TRI-LAT.EPIHUM RT/
RLMNLEHR,REFERENCE LENGTH MIN-LAT.EPIHUM RT/
RLOMXVAR,REFERENCE LENGTH OL-MAX.F.ARM RT/
RLOMDVAR,REFERENCE LENGTH OL-MID.F.ARM RT/
RLPWSTYR,REFERENCE LENGTH PROX. TO STY RT/
RLUDTRR,REFERENCE LENGTH UP.TH-TROCH RT/
RLMDDTRR,REFERENCE LENGTH MID.TH-TROCH RT/
RLMXKTIR,REFERENCE LENGTH MAX.LEG-TIB.LAT. RT/
RLMDKTIR,REFERENCE LENGTH MID.LEG-TIB.LAT. RT/
RLMNKMAR,REFERENCE LENGTH MIN.ANK-MAL.LAT. RT/


OLMXHUL,OSTEO LENGTH MAX.HUMERUS LEFT/
OGMDHUL,OSTEO GIRTH MID-HUMERUS LEFT/
OBEPIHUL,OSTEO BREADTH EPICOND.HUMERUS LEFT/
OGEPIHUL,OSTEO GIRTH EPICOND.HUMERUS LEFT/
OGMNHUL,OSTEO GIRTH MIN.HUMERUS LEFT/
OLULNL,OSTEO LENGTH ULNA LEFT/
OLRADL,OSTEO LENGTH RADIUS LEFT/
OGMDULNL,OSTEO GIRTH MID-ULNA LEFT/
OGMDRADL,OSTEO GIRTH MID-RADIUS LEFT/
OGMXULNL,OSTEO GIRTH MAX.ULNA LEFT/
OGMXRADL,OSTEO GIRTH MAX.RADIUS LEFT/
OLTROCOL,OSTEO LENGTH TROCH-FEM.COND. LEFT/
OLMXFEL,OSTEO LENGTH MAX.FEMUR LEFT/
OBEPIFEL,OSTEO BREADTH EPICOND.FEMUR LEFT/
OGEPIFEL,OSTEO GIRTH EPICOND.FEMUR LEFT/
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OGMDFEL,OSTEO GIRTH MID-FEMUR LEFT/
OGUPFEL,OSTEO GIRTH UPPER FEMUR LEFT/
OLMXTIL,OSTEO LENGTH MAX.TIBIA LEFT/
OLMXFIL,OSTEO LENGTH MAX.FIBULA LEFT/
OGMXTIL,OSTEO GIRTH MAX.TIBIA LEFT/
OGMXFIL,OSTEO GIRTH MAX.FIBULA LEFT/
OGMDTIL,OSTEO GIRTH MID-TIBIA LEFT/
OGMDFIL,OSTEO GIRTH MID-FIBULA LEFT/
OLTIMALL,OSTEO LENGTH TIBIALE-MALLEOLARE LEFT/
OLFIHMAL,OSTEO LENGTH FIB.HD-MALLEOLARE LEFT/

OLMXHUR,OSTEO  LENGTH MAX.HUMERUS RIGHT/
OGMDHUR,OSTEO GIRTH MID-HUMERUS RIGHT/
OBEPIHUR,OSTEO BREADTH EPICOND.HUMERUS RIGHT/
OGEPIHUR,OSTEO GIRTH EPICOND.HUMERUS RIGHT/
OGMNHUR,OSTEO GIRTH MIN.HUMERUS RIGHT/
OLULNR,OSTEO LENGTH ULNA RIGHT/
OLRADR,OSTEO LENGTH RADIUS RIGHT/
OGMDULNR,OSTEO GIRTH MID-ULNA RIGHT/
OGMDRADR,OSTEO GIRTH MID-RADIUS RIGHT/
OGMXULNR,OSTEO GIRTH MAX.ULNA RIGHT/
OGMXRADR,OSTEO GIRTH MAX.RADIUS RIGHT/
OLTROCOR,OSTEO LENGTH TROCH-FEM.COND. RIGHT/
OLMXFER,OSTEO LENGTH MAX.FEMUR RIGHT/
OBEPIFER,OSTEO BREADTH EPICOND.FEMUR RIGHT/
OGEPIFER,OSTEO GIRTH EPICOND.FEMUR RIGHT/
OGMDFER,OSTEO GIRTH MID-FEMUR RIGHT/
OGUPFER,OSTEO GIRTH UPPER FEMUR RIGHT/
OLMXTIR,OSTEO LENGTH MAX.TIBIA RIGHT/
OLMXFIR,OSTEO LENGTH MAX.FIBULA RIGHT/
OGMXTIR,OSTEO GIRTH MAX.TIBIA RIGHT/
OGMXFIR,OSTEO GIRTH MAX.FIBULA RIGHT/
OGMDTIR,OSTEO GIRTH MID-TIBIA RIGHT/
OGMDFIR,OSTEO GIRTH MID-FIBULA RIGHT/
OLTIMALR,OSTEO LENGTH TIBIALE-MALLEOLARE RIGHT/
OLFIHMAR,OSTEO LENGTH FIB.HD-MALLEOLARE RIGHT/
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RAW DATA for CASE NUMBER 1

SEQNUM 1. SUBFILE SS.D CASWGT 1.0000 SUBNUM 150.00 SEX 1.00 DOB 12.00 DODEM 81.00 AGEATDEM 69.00 DOANTHR 19483.00 DODISS 20483.00 LTOTHANG 172.00 LTOTSUS 172.00 LTOTSUP 169.60 WATBBWW 43600.00 WATBAWW 43600.00 WALUNH2O 0.0 WWCADCF 7840.00 WWCF 6300.00 WWCAD 1540.00 WATBBDI 43600.00 HGFHD 53.60 HGNAS 56.20 HGMAND 40.00 HLVERTRA 7.90 HLVERMEN 18.00 HLVERMAS 13.70 HLINC7 11.90 HBBITRA 14.00 HBBIZY 13.90 HDINGLAB 19.40 WAHEAD 3701.13 WWHEAD 333.20 SFHSUBL 9.70 SFSSUBL 8.10 TSFHAXL 2.10 TSFHXIL 3.10 TSFHICL 4.80 TSFHSSL 2.80 TSFHABL 3.90 TSFSAXL 1.50 TSFSXIL 2.40 TSFSICL 3.50 TSFSSSL 2.50 TSFSABL 3.10 TGAX 82.10 TGMESOST 78.60 TGTHBF 78.90 TGXIPH 73.30 TGWAI 63.10 TGHIP 80.60 TLC7CO 60.20 TBBIAC 35.30 TBMESOST 27.20 TBXIPH 27.30 TBBIILCR 31.50 TBBITROC 33.30 DAPCHMES 17.00 DAPCHXI 14.40 DBUTT 16.50 NGSUPTHY 31.20 NGINFTHY 32.70 WATR 20234.56 WWTR&C&F 5670.00 WWC&F 6300.00 WWTR -630.00 SFHSUBR 6.40 SFSSUBR 5.50 TSFHAXR 2.10 TSFHXIR 2.50 TSFHICR 4.20 TSFHSSR 2.50 TSFHABR 4.30 TSFSAXR 1.70 TSFSXIR 2.40 TSFSICR 3.50 TSFSSSR 2.20 TSFSABR 3.30 SFHTRL 3.50 SFHBIL 2.90 SFSTRL 2.60 SFSBIL 2.00 GAXARML 20.40 GTRL 18.30 GELL 20.30 GMNARML 17.30 LACRADL 33.80 BEPIHUL 6.92 WABATOTL 1049.68 WWBATOTL 13.36 LBGBAAXL 15.30 LBGBATRL 15.30 LBGBAEPL 16.30 LBBBAEPL 6.64 LBGBAPRL 14.90 WABASL 88.68 WWBASL 0.40 WABAFL 55.52 WWBAFL 2.30 WABAML 627.48 WWBAML 28.40 WABABL 278.00 WWBABL 51.50 SFHTRR 3.70 SFHBIR 1.90 SFSTRR 2.70 SFSBIR 1.50 GAXARMR 20.30 GTRR 18.00 GELR 21.60 GMNARMR 17.40 LACRADR 34.50 BEPIHUR 6.87 WABATOTR 1049.68 WWBATOTR 13.41 WABASR 88.78

WWBASR 0.50 WABAFR 63.72 WWBAFR 3.00 WABAMR 599.05 WWBAMR 27.30 WABABR 298.13 WWBABR 49.50 SFHMXFL 2.60 SFHMDFL 2.30 SFSMXFL 2.00 SFSMDFL 1.90 GMXFL 19.10 GMDFL 16.20 GPRSTYL 14.50 GBISTYL 16.20 GDISTYL 15.20 LOLSTYL 27.40 BBISTYL 6.16 WAVATOTL 615.68 WWVATOTL 13.29 WAVASL 53.43 WWVASL 1.30 WAVAFL 14.56 WWVAFL 0.0 WAVAML 375.78 WWVAML 20.30 WAVABRL 74.10 WWVABRL 17.80 WAVABUL 90.00 WWVABUL 25.00 SFHMXFR 2.30 SFHMDFR 2.10 SFSMXFR 1.90 SFSMDFR 1.80 GMXFR 20.70 GMDFR 15.40 GPRSTYR 13.60 GBISTYR 16.40 GDISTYR 15.40 LOLSTYR 28.30 BBISTYR 6.13 WAVATOTR 635.86 WWVATOTR 13.27 WAVASR 70.22 WWVASR 1.60 WAVAFR 27.96 WWVAFR 0.20 WAVAMR 360.68 WWVAMR 17.40 WAVABRR 76.10 WWVABRR 17.80 WAVABUR 88.50 WWVABUR 23.20 SFHHL 1.10 SFSHL 1.00 GMETACL 19.00 GPHAL3L 5.40 LSTYMETL 7.70 LSTYDACL 19.90 BMETACL 0.0 DMETACL 2.86 WAHATOTL 403.72 WWHATOTL 13.56 WAHSL 59.82 WWHSL 1.60 WAHFL 49.96 WWHFL 0.40 WAHML 157.54 WWHML 8.50 WAHBL 136.40 WWHBL 25.90 SFHHR 2.10 SFSHR 1.50 GMETACR 21.20 GPHAL3R 5.80 LSTYMETR 7.90 LSTYDACR 19.90 BMETACR 0.0 DMETACR 2.82 WAHATOTR 464.28 WWHATOTR 13.36 WAHSR 65.37 WWHSR -1.80 WAHFR 81.22 WWHFR 1.70 WAHMR 170.53 WWHMR 7.80 WAHBR 147.16 WWHBR 24.00 SFHANTTL 3.90 SFHMEDTL 3.00 SFHPOSTL 3.50 SFHSUPPL 0.0 SFSANTTL 3.00 SFSMEDTL 2.70 SFSPOSTL 3.10 SFSSUPPL 0.0 GUPTHL 31.40 GMDTHL 29.30 GSUPPATL 25.70 GMIDPATL 32.30 LTROTIBL 41.60 BEPIFEL 9.68 WADTOTL 4835.58 WWDTOTL 24.20 WADSL 414.33 WWDSL 1.90 WADFL 495.56 WWDFL 1.10 WADML 3034.76 WWDML 97.70 WADBFL 778.90 WWDBFL 156.40 WADBPL 39.30 WWDBPL 9.70 SFHANTTR 4.20 SFHMEDTR 2.40 SFHPOSTR 4.40 SFHSUPPR 0.0 SFSANTTR 3.50 SFSMEDTR 2.20 SFSPOSTR

3.00 SFSSUPPR 3.20 GUPTHR 30.60 GMDTHR 29.00 GSUPPATR 24.80 GMDPATR 32.00 LTROTIBR 41.90 BEPIFER 9.70 WADTOTR 4898.16 WWDTOTR 22.17 WADSR 491.01 WWDSR 23.00 WADFR 582.35 WWDFR 8.70 WADMR 2911.08 WWDMR 108.50 WADBFR 790.70 WWDBFR 160.80 WADBPR 37.60 WWDBPR 9.10 SFHMEDCL 3.10 SFSMEDCL 2.30 GINFPATL 27.80 GMXCAL 26.10 GMNANKL 18.60 GBIMALL 17.10 GMDLEGL 23.30 LTIBMALL 39.50 BCONTIL 9.37 BBIMALL 7.30 WAKTOTL 1876.30 WWKTOTL 14.22 WAKSL 136.41 WWKSL 6.60 WAKFL 185.84 WWKFL -2.80 WAKML 959.20 WWKML 32.00 WAKBTL 450.50 WWKBTL 87.80 WAKBFL 85.00 WWKBFL 20.30 SFHMEDCR 2.90 SFSMEDCR 2.40 GINFPATR 27.20 GMXCAR 24.20 GMNANKR 17.10 GBIMALR 15.90 GMDLEGR 20.20 LTIBMALR 38.80 BCONTIR 9.41 BBIMALR 7.53 WAKTOTR 1655.26 WWKTOTR 13.84 WAKSR 123.15 WWKSR 7.20 WAKFR 177.32 WWKFR -5.50 WAKMR 763.98 WWKMR 30.10 WAKBTR 452.00 WWKBTR 89.20 WAKBFR 90.10 WWKBFR 22.10 SFHFL 0.0 SFSFL 0.0 GMETATL 15.80 GPHAL1L 7.80 GARCL 26.00 LMALBALL 7.00 LAKPTEL 25.70 BHEELL 5.47 BMETATL 9.25 DMETATL 2.42 WAVTOTL 1140.00 WWVTOTL 13.67 WAVSL 118.60 WWVSL 6.50 WAVFL 234.90 WWVFL 2.00 WAVML 282.30 WWVML 11.60 WAVBL 327.00 WWVBL 55.90 SFHFR 0.0 SFSFR 0.0 GMETATR 15.40 GPHAL1R 8.20 GARCR 25.70 LMALBALR 7.30 LAKPTER 25.70 BHEELR 5.53 BMETATR 9.29 DMETATR 2.48 WAVTOTR 1020.00 WWVTOTR 13.64 WAVSR 110.90 WWVSR 6.80 WAVFR 209.50 WWVFR 1.30 WAVMR 249.60 WWVMR 9.40 WAVBR 345.70 WWVBR 61.30 WWGA&WT 67.10 WAFLBUPF 1448.00 WABUPF 666.20 WAFLPF 781.80 WAFLBUPS 0.0 WABUPS 0.0 WAFLPS 0.0 X 2.40 VOLTOT 42060.00 CAWATOTB 43198.00 DIFTOT 402.00 ADJHEAD 34.13 VOLHEAD 3367.93 CDENHEAD 1.10 ADJTR 186.57 VOLTR 20864.56 CDENTR 0.97 ADJBAL 9.68 VOLBAL 1036.32

CDENBAL 1.01 CAWABAL 1000.20 DIFBAL 49.48 ADJBASL 4.18 VOLBASL 88.28 ADJBAFL 2.62 VOLBAFL 53.22 ADJBAML 29.58 VOLBAML 599.08 ADJBABL 13.10 VOLBABL 226.50 ADJBAR 9.68 VOLBAR 1036.27 CDENBAR 1.01 CAWABAR 980.20 DIFBAR 69.48 ADJBASR 5.88 VOLBASR 88.28 ADJBAFR 4.22 VOLBAFR 60.72 ADJBAMR 39.65 VOLBAMR 571.75 ADJBABR 19.73 VOLBABR 248.63 ADJVAL 5.68 VOLVAL 602.39 DENVAL 1.02 WAVABL 171.91 CAWAVAL 587.70 DIFVAL 27.98 ADJVASL 2.43 VOLVASL 52.13 ADJVAFL 0.66 VOLVAFL 14.56 ADJVAML 17.08 VOLVAML 355.48 ADJVABL 7.81 VOLVABL 129.11 ADJVAR 5.86 VOLVAR 622.59 DENVAR 1.02 WAVABR 177.00 CAWAVAR 591.30 DIFVAR 44.56 ADJVASR 4.92 VOLVASR 68.62 ADJVAFR 1.96 VOLVAFR 27.76 ADJVAMR 25.28 VOLVAMR 343.28 ADJVABR 12.40 VOLVABR 70.70 ADJHAL 3.72 VOLHAL 390.16 CDENHAL 1.03 CAWAHAL 368.50 DIFHAL 35.22 ADJHASL 5.22 VOLHASL 58.22 ADJHAFL 4.36 VOLHAFL 49.56 ADJHAML 13.74 VOLHAML 149.04 ADJHABL 11.90 VOLHABL 110.50 ADJHAR 4.28 VOLHAR 450.92 CDENHAR 1.03 CAWAHAR 401.30 DIFHAR 62.98 ADJHASR 8.87 VOLHASR 67.17 ADJHAFR 11.02 VOLHAFR 79.52 ADJHAMR 23.13 VOLHAMR 162.73 ADJHABR 19.96 VOLHABR 123.16 ADJDL 44.58 VOLDL 4811.38 DENDL 1.01 WADBL 890.94 CAWADL 4440.80 DIFDL 394.79 ADJDSL 33.83 VOLDSL 412.43 ADJDFL 40.46 VOLDFL 494.46 ADJDML 247.76 VOLDML 2937.06 ADJDBL 72.74 VOLDBL 724.84 ADJDR 45.16 VOLDR 4875.99 DENDR 1.00 WADBR 913.73 CAWADR 4440.20 DIFDR 457.96 ADJDSR 45.91 VOLDSR 468.01 ADJDFR 54.45 VOLDFR 573.65 ADJDMR 272.18 VOLDMR 2802.58 ADJDBR 85.43 VOLDBR 715.33 ADJKL 17.30 VOLKL 1862.08 DENKL 1.01 WAKBL 594.85 CAWAKL 1689.10 DIFKL 187.20 ADJKSL 13.61 VOLKSL 129.81 ADJKFL 18.54 VOLKFL 188.64 ADJKML 95.70 VOLKML 927.20 ADJKBL

59.35 VOLKBL 486.75 ADJKR 15.26 VOLKR 1641.42 DENKR 1.01 WAKBR 590.81 CAWAKR 1518.80 DIFKR 136.46 ADJKSR 10.15 VOLKSR 115.95 ADJKFR 14.62 VOLKFR 182.82 ADJKMR 62.98 VOLKMR 733.88 ADJKBR 48.71 VOLKBR 411.51

DATA for CASE NUMBER 2

SEQNUM 2. SUBFILE SS.D CASWGT 1.0000 SUBNUM 161.00 SEX 1.00 DOB 3.00 DODEM 82.00 AGEATDEM 78.00 DOANTHR 21483.00 DODISS 22483.00 LTOTHANG 162.30 LTOTSUS 162.30 LTOTSUP 161.30 WATBBWW 66100.00 WATBAWW 66300.00 WALUNH2O 200.00 WWCADCF 7960.00 WWCF 6300.00 WWCAD 1660.00 WATBBDI 66300.00 HGFHD 55.70 HGNAS 56.50 HGMAND 56.10 HLVERTRA 13.00 HLVERMEN 19.20 HLVERMAS 15.20 HLINC7 9.10 HBBITRA 13.70 HBBIZY 12.90 HDINGLAB 19.60 WAHEAD 4532.29 WWHEAD 371.50 SFHSUBL 24.30 SFSSUBL 18.90 TSFHAXL 8.90 TSFHXIL 0.0 TSFHICL 10.80 TSFHSSL 13.00 TSFHABL 0.0 TSFSAXL 13.00 TSFSXIL 0.0 TSFSICL 9.40 TSFSSSL 9.70 TSFSABL 0.0 TGAX 96.70 TGMESOST 95.30 TGTHBF 94.90 TGXIPH 93.30 TGWAI 88.50 TGHIP 91.40 TLC7CO 63.20 TBBIAC 35.10 TBMESOST 30.80 TBXIPH 30.60 TBBIILCR 29.00 TBBITROC 29.00 DAPCHMES 20.40 DAPCHXI 22.70 DBUTT 17.60 NGSUPTHY 46.10 NGINFTHY 43.90 WATR 33465.82 WWTR&C&F 6270.00 WWC&F 6300.00 WWTR -30.00 SFHSUBR 25.80 SFSSUBR 20.90 TSFHAXR 6.80 TSFHXIR 0.0 TSFHICR 16.30 TSFHSSR 10.00 TSFHABR 0.0 TSFSAXR 9.30 TSFSXIR 0.0 TSFSICR 13.10 TSFSSSR 8.60 TSFSABR 0.0 SFHTRL 19.20 SFHBIL 11.90 SFSTRL 15.20 SFSBIL 7.60 GAXARML 28.90 GTRL 28.80 GELL 24.80 GMNARML 0.0 LACRADL 32.20 BEPIHUL 6.62 WABATOTL 1650.12 WWBATOTL 50.10 LBGBAAXL 18.10 LBGBATRL 18.50 LBGBAEPL

17.10 LBBBAEPL 6.20 LBGBAPRL 16.40 WABASL 134.88 WWBASL 5.80 WABAFL 593.26 WWBAFL -27.90 WABAML 705.20 WWBAML 25.30 WABABL 216.78 WWBABL 36.10 SFHTRR 24.90 SFHBIR 13.10 SFSTRR 17.60 SFSBIR 9.70 GAXARMR 28.80 GTRR 27.80 GELR 23.80 GMNARMR 0.0 LACRADR 32.10 BEPIHUR 6.63 WABATOTR 1660.19 WWBATOTR 47.90 WABASR 137.30 WWBASR 6.80 WABAFR 620.75 WWBAFR -26.80 WABAMR 670.44 WWBAMR 22.50 WABABR 231.71 WWBABR 35.50 SFHMXFL 10.00 SFHMDFL 7.50 SFSMXFL 8.60 SFSMDFL 6.50 GMXFL 23.70 GMDFL 19.30 GPRSTYL 15.50 GBISTYL 15.70 GDISTYL 15.00 LOLSTYL 26.20 BBISTYL 5.12 WAVATOTL 829.09 WWVATOTL 49.30 WAVASL 56.95 WWVASL 2.80 WAVAFL 200.26 WWVAFL -8.60 WAVAML 449.32 WWVAML 20.20 WAVABRL 52.30 WWVABRL 9.90 WAVABUL 63.50 WWVABUL 14.30 SFHMXFR 9.00 SFHMDFR 5.80 SFSMXFR 7.20 SFSMDFR 5.20 GMXFR 23.70 GMDFR 19.00 GPRSTYR 15.60 GBISTYR 15.40 GDISTYR 14.60 LOLSTYR 26.20 BBISTYR 5.28 WAVATOTR 893.56 WWVATOTR 43.50 WAVASR 67.74 WWVASR 2.90 WAVAFR 216.58 WWVAFR -7.70 WAVAMR 485.21 WWVAMR 18.40 WAVABRR 51.60 WWVABRR 9.10 WAVABUR 65.40 WWVABUR 14.00 SFHHL 1.40 SFSHL 1.50 GMETACL 18.50 GPHAL3L 5.90 LSTYMETL 7.50 LSTYDACL 17.60 BMETACL 7.32 DMETACL 2.48 WAHATOTL 342.52 WWHATOTL 23.50 WAHSL 52.67 WWHSL 1.80 WAHFL 74.00 WWHFL -1.60 WAHML 126.24 WWHML 4.50 WAHBL 89.61 WWHBL 13.30 SFHHR 2.10 SFSHR 1.70 GMETACR 18.50 GPHAL3R 6.20 LSTYMETR 7.30 LSTYDACR 16.70 BMETACR 7.46 DMETACR 2.42 WAHATOTR 353.60 WWHATOTR 24.90 WAHSR 45.44 WWHSR 1.90 WAHFR 108.47 WWHFR -1.40 WAHMR 107.68 WWHMR 4.40 WAHBR 92.01 WWHBR 14.00 SFHANTTL 11.30 SFHMEDTL 7.80 SFHPOSTL 19.90 SFHSUPPL 11.70 SFSANTTL 9.80 SFSMEDTL 7.20 SFSPOSTL 12.30 SFSSUPPL 6.40 GUPTHL

48.80 GMDTHL 40.20 GSUPPATL 36.00 GMIDPATL 35.60 LTROTIBL 42.90 BEPIFEL 9.57 WADTOTL 8200.23 WWDTOTL 193.70 WADSL 489.89 WWDSL 24.50 WADFL 2885.48 WWDFL -130.90 WADML 4079.63 WWDML 106.00 WADBFL 673.50 WWDBFL 123.40 WADBPL 21.40 WWDBPL 4.20 SFHANTTR 8.70 SFHMEDTR 11.80 SFHPOSTR 20.70 SFHSUPPR 8.70 SFSANTTR 4.90 SFSMEDTR 8.20 SFSPOSTR 11.40 SFSSUPPR 4.50 GUPTHR 47.90 GMDTHR 39.00 GSUPPATR 35.70 GMDPATR 35.00 LTROTIBR 42.80 BEPIFER 9.68 WADTOTR 8391.64 WWDTOTR 193.40 WADSR 492.72 WWDSR 23.80 WADFR 3025.52 WWDFR -138.80 WADMR 4113.73 WWDMR 114.00 WADBFR 678.90 WWDBFR 122.80 WADBPR 20.30 WWDBPR 4.40 SFHMEDCL 7.70 SFSMEDCL 5.80 GINFPATL 32.60 GMXCAL 30.60 GMNANKL 19.70 GBIMALL 24.00 GMDLEGL 25.90 LTIBMALL 38.20 BCONTIL 9.67 BBIMALL 7.11 WAKTOTL 2195.12 WWKTOTL 143.20 WAKSL 131.22 WWKSL 7.00 WAKFL 366.63 WWKFL -12.40 WAKML 1217.44 WWKML 41.80 WAKBTL 386.10 WWKBTL 63.70 WAKBFL 66.60 WWKBFL 12.60 SFHMEDCR 7.50 SFSMEDCR 4.20 GINFPATR 30.00 GMXCAR 30.70 GMNANKR 19.40 GBIMALR 24.80 GMDLEGR 35.80 LTIBMALR 38.30 BCONTIR 9.60 BBIMALR 6.72 WAKTOTR 2163.89 WWKTOTR 144.60 WAKSR 109.98 WWKSR 6.90 WAKFR 348.95 WWKFR -15.80 WAKMR 1211.15 WWKMR 45.80 WAKBTR 392.20 WWKBTR 63.20 WAKBFR 64.90 WWKBFR 12.30 SFHFL 0.0 SFSFL 0.0 GMETATL 22.70 GPHAL1L 8.10 GARCL 23.70 LMALBALL 6.00 LAKPTEL 21.80 BHEELL 5.73 BMETATL 8.54 DMETATL 2.63 WAVTOTL 823.00 WWVTOTL 53.10 WAVSL 90.80 WWVSL 5.80 WAVFL 215.40 WWVFL -2.50 WAVML 214.50 WWVML 10.10 WAVBL 230.70 WWVBL 34.40 SFHFR 0.0 SFSFR 0.0 GMETATR 22.30 GPHAL1R 7.50 GARCR 23.70 LMALBALR 6.60 LAKPTER 21.60 BHEELR 5.94 BMETATR 8.48 DMETATR 2.61 WAVTOTR 787.00 WWVTOTR 52.10 WAVSR 87.60 WWVSR

4.90 WAVFR 264.30 WWVFR 0.40 WAVMR 151.60 WWVMR 5.20 WAVBR 238.50 WWVBR 35.90 WWGA&WT 89.70 WAFLBUPF 1850.00 WABUPF 262.90 WAFLPF 1587.10 WAFLBUPS 0.0 WABUPS 0.0 WAFLPS 0.0 X 1.00 VOLTOT 64640.00 CAWATOTB 65813.00 DIFTOT 487.00 ADJHEAD 33.29 VOLHEAD 4160.79 CDENHEAD 1.09 ADJTR 245.82 VOLTR 33495.82 CDENTR 1.00 ADJBAL 12.12 VOLBAL 1600.02 CDENBAL 1.03 CAWABAL 1581.80 DIFBAL 68.32 ADJBASL 5.58 VOLBASL 129.08 ADJBAFL 24.56 VOLBAFL 621.16 ADJBAML 29.20 VOLBAML 679.90 ADJBABL 8.98 VOLBABL 180.68 ADJBAR 12.19 VOLBAR 1612.29 CDENBAR 1.03 CAWABAR 1540.50 DIFBAR 119.69 ADJBASR 9.90 VOLBASR 130.50 ADJBAFR 44.75 VOLBAFR 647.55 ADJBAMR 48.34 VOLBAMR 647.94 ADJBABR 16.71 VOLBABR 196.21 ADJVAL 6.09 VOLVAL 779.79 DENVAL 1.06 WAVABL 122.57 CAWAVAL 783.30 DIFVAL 45.79 ADJVASL 3.15 VOLVASL 54.15 ADJVAFL 11.06 VOLVAFL 208.86 ADJVAML 24.82 VOLVAML 429.12 ADJVABL 6.77 VOLVABL 98.37 ADJVAR 6.56 VOLVAR 850.06 DENVAR 1.05 WAVABR 124.03 CAWAVAR 842.90 DIFVAR 50.66 ADJVASR 3.84 VOLVASR 64.84 ADJVAFR 12.28 VOLVAFR 224.28 ADJVAMR 27.51 VOLVAMR 466.81 ADJVABR 7.03 VOLVABR 49.53 ADJHAL 2.52 VOLHAL 319.02 CDENHAL 1.07 CAWAHAL 318.00 DIFHAL 24.52 ADJHASL 3.77 VOLHASL 50.87 ADJHAFL 5.30 VOLHAFL 75.60 ADJHAML 9.04 VOLHAML 121.74 ADJHABL 6.41 VOLHABL 76.31 ADJHAR 2.60 VOLHAR 328.70 CDENHAR 1.08 CAWAHAR 313.60 DIFHAR 40.00 ADJHASR 5.14 VOLHASR 43.54 ADJHAFR 12.27 VOLHAFR 109.87 ADJHAMR 12.18 VOLHAMR 103.28 ADJHABR 10.41 VOLHABR 78.01 ADJDL 60.23 VOLDL 8006.53 DENDL 1.02 WADBL 745.23 CAWADL 7646.39 DIFDL 553.84 ADJDSL 33.09 VOLDSL 465.39 ADJDFL 194.88 VOLDFL 3016.38 ADJDML 275.53 VOLDML 3973.63 ADJDBL 50.33 VOLDBL 617.63 ADJDR

61.64 VOLDR 8198.23 DENDR 1.02 WADBR 759.67 CAWADR 7723.70 DIFDR 667.94 ADJDSR 39.22 VOLDSR 468.92 ADJDFR 240.82 VOLDFR 3164.32 ADJDMR 327.44 VOLDMR 3999.74 ADJDBR 60.47 VOLDBR 616.57 ADJKL 16.12 VOLKL 2051.92 DENKL 1.07 WAKBL 479.83 CAWAKL 2071.00 DIFKL 124.12 ADJKSL 7.42 VOLKSL 124.22 ADJKFL 20.73 VOLKFL 379.03 ADJKML 68.84 VOLKML 1175.64 ADJKBL 27.13 VOLKBL 403.53 ADJKR 15.89 VOLKR 2019.29 DENKR 1.07 WAKBR 493.82 CAWAKR 2003.00 DIFKR 160.90 ADJKSR 8.18 VOLKSR 103.08 ADJKFR 25.95 VOLKFR 364.75 ADJKMR 90.05 VOLKMR 1165.35 ADJKBR 36.72 VOLKBR 365.72

DATA for CASE NUMBER 3

SEQNUM 3. SUBFILE SS.D CASWGT 1.0000 SUBNUM 189.00 SEX 2.00 DOB 3.00 DODEM 82.00 AGEATDEM 79.00 DOANTHR 25483.00 DODISS 26483.00 LTOTHANG 149.00 LTOTSUS 149.00 LTOTSUP 148.50 WATBBWW 50800.00 WATBAWW 51000.00 WALUNH2O 200.00 WWCADCF 6390.00 WWCF 6300.00 WWCAD 90.00 WATBBDI 50900.00 HGFHD 52.70 HGNAS 53.30 HGMAND 45.70 HLVERTRA 11.00 HLVERMEN 18.80 HLVERMAS 14.90 HLINC7 12.00 HBBITRA 13.90 HBBIZY 13.40 HDINGLAB 15.90 WAHEAD 3701.12 WWHEAD 290.20 SFHSUBL 34.40 SFSSUBL 12.90 TSFHAXL 20.40 TSFHXIL 22.60 TSFHICL 23.80 TSFHSSL 10.90 TSFHABL 15.70 TSFSAXL 17.60 TSFSXIL 11.90 TSFSICL 19.10 TSFSSSL 10.90 TSFSABL 14.30 TGAX 83.20 TGMESOST 85.70 TGTHBF 80.70 TGXIPH 80.70 TGWAI 78.50 TGHIP 89.50 TLC7CO 52.40 TBBIAC 29.90 TBMESOST 26.80 TBXIPH 26.30 TBBIILCR 29.20 TBBITROC 32.10 DAPCHMES 17.60 DAPCHXI 18.30 DBUTT 17.10 NGSUPTHY 41.20 NGINFTHY 38.70 WATR 24262.70 WWTR&C&F 5848.00 WWC&F 6300.00 WWTR -452.00 SFHSUBR 17.10 SFSSUBR 20.00 TSFHAXR

16.90 TSFHXIR 15.20 TSFHICR 27.50 TSFHSSR 18.30 TSFHABR 5.70 TSFSAXR 16.50 TSFSXIR 14.60 TSFSICR 25.40 TSFSSSR 14.80 TSFSABR 4.50 SFHTRL 16.70 SFHBIL 11.50 SFSTRL 13.70 SFSBIL 11.30 GAXARML 24.60 GTRL 24.20 GELL 22.80 GMNARML 22.60 LACRADL 30.30 BEPIHUL 5.11 WABATOTL 1347.31 WWBATOTL 14.80 LBGBAAXL 13.60 LBGBATRL 12.80 LBGBAEPL 15.40 LBBBAEPL 5.88 LBGBAPRL 13.10 WABASL 43.17 WWBASL 0.80 WABAFL 710.43 WWBAFL -40.90 WABAML 439.76 WWBAML 14.30 WABABL 153.96 WWBABL 25.10 SFHTRR 17.40 SFHBIR 15.90 SFSTRR 14.00 SFSBIR 14.20 GAXARMR 27.80 GTRR 28.60 GELR 21.50 GMNARMR 27.10 LACRADR 30.10 BEPIHUR 6.46 WABATOTR 1582.10 WWBATOTR 25.10 WABASR 106.56 WWBASR 4.40 WABAFR 754.73 WWBAFR -36.50 WABAMR 566.91 WWBAMR 17.00 WABABR 153.90 WWBABR 25.20 SFHMXFL 14.10 SFHMDFL 12.10 SFSMXFL 10.10 SFSMDFL 10.50 GMXFL 21.80 GMDFL 21.60 GPRSTYL 16.40 GBISTYL 15.20 GDISTYL 13.70 LOLSTYL 22.60 BBISTYL 5.06 WAVATOTL 797.33 WWVATOTL 13.20 WAVASL 95.76 WWVASL 3.70 WAVAFL 369.20 WWVAFL -20.90 WAVAML 252.96 WWVAML 9.30 WAVABRL 34.20 WWVABRL 7.20 WAVABUL 38.70 WWVABUL 9.80 SFHMXFR 14.90 SFHMDFR 16.40 SFSMXFR 12.40 SFSMDFR 15.00 GMXFR 21.80 GMDFR 17.30 GPRSTYR 14.40 GBISTYR 14.60 GDISTYR 13.60 LOLSTYR 22.50 BBISTYR 5.05 WAVATOTR 550.28 WWVATOTR 25.20 WAVASR 27.52 WWVASR 1.20 WAVAFR 186.92 WWVAFR -9.80 WAVAMR 253.58 WWVAMR 9.00 WAVABRR 36.50 WWVABRR 7.90 WAVABUR 42.10 WWVABUR 11.10 SFHHL 1.90 SFSHL 2.20 GMETACL 16.00 GPHAL3L 5.40 LSTYMETL 6.50 LSTYDACL 15.70 BMETACL 6.35 DMETACL 1.96 WAHATOTL 246.95 WWHATOTL 15.40 WAHSL 37.24 WWHSL 1.80 WAHFL 70.56 WWHFL -2.50 WAHML 70.77 WWHML 3.10 WAHBL 68.38 WWHBL 9.00 SFHHR 2.00

SFSHR 1.30 GMETACR 16.40 GPHAL3R 5.60 LSTYMETR 7.50 LSTYDACR 17.00 BMETACR 6.83 DMETACR 1.88 WAHATOTR 259.61 WWHATOTR 18.30 WAHSR 46.84 WWHSR 2.00 WAHFR 82.47 WWHFR -1.20 WAHMR 54.21 WWHMR 2.50 WAHBR 76.09 WWHBR 11.00 SFHANTTL 14.80 SFHMEDTL 35.30 SFHPOSTL 19.20 SFHSUPPL 17.80 SFSANTTL 12.00 SFSMEDTL 29.20 SFSPOSTL 17.10 SFSSUPPL 17.60 GUPTHL 43.20 GMDTHL 33.50 GSUPPATL 31.80 GMIDPATL 33.90 LTROTIBL 38.50 BEPIFEL 8.86 WADTOTL 6613.45 WWDTOTL -16.00 WADSL 352.56 WWDSL 12.90 WADFL 3622.10 WWDFL -185.80 WADML 2120.21 WWDML 37.50 WADBFL 470.30 WWDBFL 68.90 WADBPL 22.00 WWDBPL 2.50 SFHANTTR 11.40 SFHMEDTR 34.80 SFHPOSTR 26.20 SFHSUPPR 14.10 SFSANTTR 13.40 SFSMEDTR 28.80 SFSPOSTR 22.30 SFSSUPPR 9.10 GUPTHR 46.90 GMDTHR 37.20 GSUPPATR 35.30 GMDPATR 36.40 LTROTIBR 37.30 BEPIFER 9.85 WADTOTR 7025.53 WWDTOTR 12.20 WADSR 405.29 WWDSR 17.50 WADFR 3502.56 WWDFR -170.90 WADMR 2561.97 WWDMR 34.40 WADBFR 497.60 WWDBFR 70.30 WADBPR 19.60 WWDBPR 1.50 SFHMEDCL 24.00 SFSMEDCL 23.00 GINFPATL 30.50 GMXCAL 26.80 GMNANKL 28.90 GBIMALL 24.70 GMDLEGL 22.60 LTIBMALL 33.00 BCONTIL 8.30 BBIMALL 6.55 WAKTOTL 1555.16 WWKTOTL 28.10 WAKSL 80.82 WWKSL 0.40 WAKFL 620.86 WWKFL -34.20 WAKML 544.29 WWKML 9.90 WAKBTL 258.60 WWKBTL 31.60 WAKBFL 39.80 WWKBFL 6.70 SFHMEDCR 25.60 SFSMEDCR 6.70 GINFPATR 33.70 GMXCAR 29.20 GMNANKR 18.80 GBIMALR 26.20 GMDLEGR 24.40 LTIBMALR 34.10 BCONTIR 9.12 BBIMALR 6.35 WAKTOTR 1634.47 WWKTOTR 40.60 WAKSR 97.85 WWKSR 0.10 WAKFR 656.21 WWKFR -30.00 WAKMR 541.87 WWKMR 11.80 WAKBTR 260.90 WWKBTR 31.60 WAKBFR 40.80 WWKBFR 6.60 SFHFL 1.80 SFSFL 1.80 GMETATL 20.20 GPHAL1L 6.90 GARCL 22.00 LMALBALL 5.10

LAKPTEL 19.40 BHEELL 6.93 BMETATL 7.33 DMETATL 2.09 WAVTOTL 630.10 WWVTOTL 19.70 WAVSL 64.70 WWVSL 3.70 WAVFL 259.60 WWVFL -7.40 WAVML 99.60 WWVML 2.60 WAVBL 170.40 WWVBL 14.30 SFHFR 2.00 SFSFR 1.60 GMETATR 20.80 GPHAL1R 6.70 GARCR 23.40 LMALBALR 5.00 LAKPTER 20.80 BHEELR 6.42 BMETATR 7.50 DMETATR 2.65 WAVTOTR 687.20 WWVTOTR 22.20 WAVSR 67.90 WWVSR 3.40 WAVFR 225.10 WWVFR -7.40 WAVMR 153.20 WWVMR 3.10 WAVBR 172.80 WWVBR 14.80 WWGA&WT 89.70 WAFLBUPF 820.90 WABUPF 253.80 WAFLPF 567.10 WAFLBUPS 854.10 WABUPS 646.80 WAFLPS 107.30 X 0.50 VOLTOT 50810.00 CAWATOTB 50642.58 DIFTOT 257.42 ADJHEAD 18.72 VOLHEAD 3410.92 CDENHEAD 1.09 ADJTR 122.70 VOLTR 24714.70 CDENTR 0.98 ADJBAL 6.81 VOLBAL 1332.51 CDENBAL 1.01 CAWABAL 1273.30 DIFBAL 74.01 ADJBASL 2.37 VOLBASL 42.37 ADJBAFL 39.03 VOLBAFL 751.33 ADJBAML 24.16 VOLBAML 425.46 ADJBABL 8.46 VOLBABL 128.86 ADJBAR 8.00 VOLBAR 1557.00 CDENBAR 1.02 CAWABAR 1520.40 DIFBAR 61.70 ADJBASR 4.16 VOLBASR 102.16 ADJBAFR 29.43 VOLBAFR 791.23 ADJBAMR 22.11 VOLBAMR 549.91 ADJBABR 6.00 VOLBABR 128.70 ADJVAL 4.03 VOLVAL 784.13 DENVAL 1.02 WAVABL 79.42 CAWAVAL 731.90 DIFVAL 65.43 ADJVASL 7.86 VOLVASL 92.06 ADJVAFL 30.30 VOLVAFL 390.10 ADJVAML 20.76 VOLVAML 243.66 ADJVABL 6.52 VOLVABL 62.42 ADJVAR 2.78 VOLVAR 525.08 DENVAR 1.05 WAVABR 82.26 CAWAVAR 525.80 DIFVAR 24.48 ADJVASR 1.22 VOLVASR 26.32 ADJVAFR 8.32 VOLVAFR 196.72 ADJVAMR 11.28 VOLVAMR 244.58 ADJVABR 3.66 VOLVABR 32.26 ADJHAL 1.25 VOLHAL 231.55 CDENHAL 1.07 CAWAHAL 226.80 DIFHAL 20.15 ADJHASL 3.04 VOLHASL 35.44 ADJHAFL 5.76 VOLHAFL 73.06 ADJHAML 5.77 VOLHAML 67.67 ADJHABL 5.58 VOLHABL 59.38 ADJHAR 1.31 VOLHAR

241.31 CDENHAR 1.08 CAWAHAR 236.10 DIFHAR 23.51 ADJHASR 4.24 VOLHASR 44.84 ADJHAFR 7.47 VOLHAFR 83.67 ADJHAMR 4.91 VOLHAMR 51.71 ADJHABR 6.89 VOLHABR 65.09 ADJDL 33.45 VOLDL 6629.45 DENDL 1.00 WADBL 518.57 CAWADL 6278.39 DIFDL 335.05 ADJDSL 17.86 VOLDSL 339.66 ADJDFL 183.50 VOLDFL 3807.90 ADJDML 107.41 VOLDML 2082.71 ADJDBL 26.27 VOLDBL 447.17 ADJDR 35.53 VOLDR 7013.32 DENDR 1.00 WADBR 555.72 CAWADR 6538.60 DIFDR 486.93 ADJDSR 28.09 VOLDSR 387.79 ADJDFR 242.76 VOLDFR 3673.46 ADJDMR 177.57 VOLDMR 2527.57 ADJDBR 38.52 VOLDBR 465.82 ADJKL 7.86 VOLKL 1527.06 DENKL 1.02 WAKBL 309.19 CAWAKL 1500.90 DIFKL 54.27 ADJKSL 2.82 VOLKSL 80.42 ADJKFL 21.66 VOLKFL 655.06 ADJKML 18.99 VOLKML 534.39 ADJKBL 10.79 VOLKBL 270.89 ADJKR 8.27 VOLKR 1593.87 DENKR 1.03 WAKBR 338.54 CAWAKR 1456.60 DIFKR 177.87 ADJKSR 10.65 VOLKSR 97.75 ADJKFR 71.41 VOLKFR 686.21 ADJKMR 58.97 VOLKMR 530.07 ADJKBR 36.84 VOLKBR 266.14

DATA for CASE NUMBER 4

SEQNUM 4. SUBFILE SS.D CASWGT 1.0000 SUBNUM 138.00 SEX 1.00 DOB 65.00 DODEM 81.00 AGEATDEM 16.00 DOANTHR 28483.00 DODISS 29483.00 LTOTHANG 179.30 LTOTSUS 179.30 LTOTSUP 178.40 WATBBWW 80000.00 WATBAWW 80300.00 WALUNH2O 300.00 WWCADCF 7935.00 WWCF 6300.00 WWCAD 1640.00 WATBBDI 80100.00 HGFHD 59.10 HGNAS 59.10 HGMAND 50.50 HLVERTRA 11.10 HLVERMEN 22.10 HLVERMAS 13.80 HLINC7 12.50 HBBITRA 14.60 HBBIZY 13.00 HDINGLAB 19.30 WAHEAD 5174.56 WWHEAD 458.10 SFHSUBL 14.00 SFSSUBL 12.30 TSFHAXL 10.70 TSFHXIL 9.80 TSFHICL 25.70 TSFHSSL 9.20 TSFHABL 11.90 TSFSAXL 10.20

TSFSXIL 14.70 TSFSICL 24.00 TSFSSSL 5.00 TSFSABL 9.30 TGAX 100.50 TGMESOST 101.30 TGTHBF 101.40 TGXIPH 92.70 TGWAI 84.80 TGHIP 97.90 TLC7CO 60.70 TBBIAC 38.50 TBMESOST 32.90 TBXIPH 30.40 TBBIILCR 27.60 TBBITROC 32.10 DAPCHMES 19.70 DAPCHXI 23.30 DBUTT 20.40 NGSUPTHY 40.10 NGINFTHY 40.70 WATR 35336.04 WWTR&C&F 5605.00 WWC&F 6300.00 WWTR -695.00 SFHSUBR 17.20 SFSSUBR 17.20 TSFHAXR 12.10 TSFHXIR 11.70 TSFHICR 24.90 TSFHSSR 8.00 TSFHABR 10.80 TSFSAXR 9.60 TSFSXIR 12.40 TSFSICR 25.20 TSFSSSR 7.50 TSFSABR 7.90 SFHTRL 28.90 SFHBIL 14.50 SFSTRL 22.70 SFSBIL 13.10 GAXARML 32.30 GTRL 30.90 GELL 26.30 GMNARML 27.40 LACRADL 35.10 BEPIHUL 7.46 WABATOTL 2267.35 WWBATOTL 107.90 LBGBAAXL 20.30 LBGBATRL 21.40 LBGBAEPL 20.30 LBBBAEPL 7.02 LBGBAPRL 18.50 WABASL 162.03 WWBASL 10.70 WABAFL 791.51 WWBAFL -38.40 WABAML 1041.54 WWBAML 62.40 WABABL 272.26 WWBABL 60.80 SFHTRR 24.60 SFHBIR 14.50 SFSTRR 20.50 SFSBIR 11.10 GAXARMR 31.10 GTRR 30.10 GELR 26.40 GMNARMR 26.40 LACRADR 35.00 BEPIHUR 7.63 WABATOTR 2225.67 WWBATOTR 119.20 WABASR 147.14 WWBASR 9.60 WABAFR 730.84 WWBAFR -33.00 WABAMR 1069.92 WWBAMR 64.80 WABABR 277.76 WWBABR 65.00 SFHMXFL 14.00 SFHMDFL 15.60 SFSMXFL 14.50 SFSMDFL 12.10 GMXFL 27.30 GMDFL 23.10 GPRSTYL 17.70 GBISTYL 17.30 GDISTYL 17.20 LOLSTYL 28.60 BBISTYL 5.59 WAVATOTL 1116.16 WWVATOTL 83.90 WAVASL 85.49 WWVASL 6.60 WAVAFL 236.04 WWVAFL -9.60 WAVAML 649.16 WWVAML 37.40 WAVABRL 66.00 WWVABRL 18.10 WAVABUL 77.10 WWVABUL 22.70 SFHMXFR 14.50 SFHMDFR 12.90 SFSMXFR 13.40 SFSMDFR 9.70 GMXFR 26.40 GMDFR 22.40 GPRSTYR 17.30 GBISTYR 17.00 GDISTYR 16.20 LOLSTYR 27.00 BBISTYR 5.80 WAVATOTR 1117.67 WWVATOTR 89.20

WAVASR 79.96 WWVASR 7.50 WAVAFR 224.08 WWVAFR -8.00 WAVAMR 666.85 WWVAMR 42.00 WAVABRR 68.20 WWVABRR 18.80 WAVABUR 75.90 WWVABUR 22.50 SFHHL 4.60 SFSHL 3.80 GMETACL 19.40 GPHAL3L 6.00 LSTYMETL 8.20 LSTYDACL 19.60 BMETACL 7.92 DMETACL 2.52 WAHATOTL 452.82 WWHATOTL 44.80 WAHSL 86.94 WWHSL 7.00 WAHFL 74.45 WWHFL 0.0 WAHML 179.09 WWHML 11.20 WAHBL 112.35 WWHBL 22.20 SFHHR 4.80 SFSHR 3.20 GMETACR 19.00 GPHAL3R 5.80 LSTYMETR 8.10 LSTYDACR 19.20 BMETACR 8.02 DMETACR 2.52 WAHATOTR 429.57 WWHATOTR 45.90 WAHSR 84.87 WWHSR 7.20 WAHFR 79.42 WWHFR 1.30 WAHMR 144.76 WWHMR 9.60 WAHBR 120.52 WWHBR 24.50 SFHANTTL 32.00 SFHMEDTL 29.20 SFHPOSTL 31.70 SFHSUPPL 22.80 SFSANTTL 25.00 SFSMEDTL 28.30 SFSPOSTL 27.50 SFSSUPPL 18.00 GUPTHL 56.30 GMDTHL 48.30 GSUPPATL 40.20 GMIDPATL 39.70 LTROTIBL 45.70 BEPIFEL 10.69 WADTOTL 11406.19 WWDTOTL 258.10 WADSL 519.17 WWDSL 42.00 WADFL 4717.53 WWDFL -285.30 WADML 5296.20 WWDML 290.60 WADBFL 820.50 WWDBFL 171.20 WADBPL 36.70 WWDBPL 7.30 SFHANTTR 23.60 SFHMEDTR 22.60 SFHPOSTR 30.10 SFHSUPPR 23.90 SFSANTTR 23.40 SFSMEDTR 21.20 SFSPOSTR 27.20 SFSSUPPR 20.70 GUPTHR 57.80 GMDTHR 48.60 GSUPPATR 41.30 GMDPATR 40.70 LTROTIBR 45.90 BEPIFER 11.00 WADTOTR 11728.34 WWDTOTR 234.40 WADSR 636.44 WWDSR 40.80 WADFR 4874.50 WWDFR -306.00 WADMR 5368.28 WWDMR 298.40 WADBFR 806.00 WWDBFR 166.70 WADBPR 35.60 WWDBPR 6.80 SFHMEDCL 22.70 SFSMEDCL 21.30 GINFPATL 34.90 GMXCAL 35.00 GMNANKL 23.20 GBIMALL 26.30 GMDLEGL 31.00 LTIBMALL 42.10 BCONTIL 10.32 BBIMALL 7.58 WAKTOTL 3252.32 WWKTOTL 199.10 WAKSL 197.26 WWKSL 18.10 WAKFL 961.06 WWKFL -48.10 WAKML 1515.35 WWKML 84.70 WAKBTL 495.90 WWKBTL 102.00

WAKBFL 72.00 WWKBFL 20.40 SFHMEDCR 22.20 SFSMEDCR 18.30 GINFPATR 36.30 GMXCAR 36.70 GMNANKR 24.20 GBIMALR 26.80 GMDLEGR 32.70 LTIBMALR 40.90 BCONTIR 10.31 BBIMALR 7.63 WAKTOTR 3438.97 WWKTOTR 209.40 WAKSR 239.94 WWKSR 16.80 WAKFR 1019.18 WWKFR -50.30 WAKMR 1580.54 WWKMR 85.00 WAKBTR 517.20 WWKBTR 106.20 WAKBFR 72.00 WWKBFR 20.50 SFHFL 0.0 SFSFL 0.0 GMETATL 21.00 GPHAL1L 7.20 GARCL 24.20 LMALBALL 6.00 LAKPTEL 27.40 BHEELL 4.85 BMETATL 8.45 DMETATL 2.65 WAVTOTL 1030.50 WWVTOTL 86.00 WAVSL 175.20 WWVSL 9.10 WAVFL 181.20 WWVFL -0.30 WAVML 313.10 WWVML 13.70 WAVBL 331.00 WWVBL 59.00 SFHFR 0.0 SFSFR 0.0 GMETATR 21.30 GPHAL1R 7.80 GARCR 26.90 LMALBALR 6.10 LAKPTER 27.00 BHEELR 5.14 BMETATR 8.50 DMETATR 2.62 WAVTOTR 1109.50 WWVTOTR 83.80 WAVSR 167.70 WWVSR 10.50 WAVFR 248.00 WWVFR -0.20 WAVMR 318.40 WWVMR 15.40 WAVBR 346.80 WWVBR 61.20 WWGA&WT 89.40 WAFLBUPF 676.30 WABUPF 549.20 WAFLPF 127.10 WAFLBUPS 596.40 WABUPS 338.10 WAFLPS 258.30 X 0.90 VOLTOT 78460.00 CAWATOTB 79564.94 DIFTOT 535.06 ADJHEAD 34.57 VOLHEAD 4716.46 CDENHEAD 1.10 ADJTR 236.04 VOLTR 36031.04 CDENTR 0.98 ADJBAL 15.15 VOLBAL 2159.45 CDENBAL 1.05 CAWABAL 2223.50 DIFBAL 43.85 ADJBASL 3.13 VOLBASL 151.33 ADJBAFL 15.31 VOLBAFL 829.91 ADJBAML 20.14 VOLBAML 979.14 ADJBABL 5.27 VOLBABL 211.47 ADJBAR 14.87 VOLBAR 2106.47 CDENBAR 1.06 CAWABAR 2196.30 DIFBAR 29.37 ADJBASR 1.94 VOLBASR 137.54 ADJBAFR 9.64 VOLBAFR 763.84 ADJBAMR 14.12 VOLBAMR 1005.12 ADJBABR 3.67 VOLBABR 212.76 ADJVAL 7.46 VOLVAL 1032.26 DENVAL 1.08 WAVABL 145.47 CAWAVAL 1098.00 DIFVAL 18.16 ADJVASL 1.39 VOLVASL 78.89 ADJVAFL 3.84 VOLVAFL 245.64 ADJVAML 10.56 VOLVAML 611.76 ADJVABL

2.37 VOLVABL 104.67 ADJVAR 7.47 VOLVAR 1028.47 DENVAR 1.09 WAVABR 146.77 CAWAVAR 1097.30 DIFVAR 20.37 ADJVASR 1.46 VOLVASR 72.46 ADJVAFR 4.08 VOLVAFR 232.08 ADJVAMR 12.15 VOLVAMR 624.85 ADJVABR 2.67 VOLVABR 52.07 ADJHAL 3.02 VOLHAL 408.02 CDENHAL 1.11 CAWAHAL 434.90 DIFHAL 17.92 ADJHASL 3.44 VOLHASL 79.94 ADJHAFL 2.95 VOLHAFL 74.45 ADJHAML 7.09 VOLHAML 167.89 ADJHABL 4.45 VOLHABL 90.15 ADJHAR 2.87 VOLHAR 383.67 CDENHAR 1.12 CAWAHAR 402.40 DIFHAR 27.17 ADJHASR 5.37 VOLHASR 77.67 ADJHAFR 5.02 VOLHAFR 78.12 ADJHAMR 9.16 VOLHAMR 135.16 ADJHABR 7.62 VOLHABR 96.02 ADJDL 76.19 VOLDL 11148.09 DENDL 1.02 WADBL 873.29 CAWADL 11195.99 DIFDL 210.20 ADJDSL 9.57 VOLDSL 477.17 ADJDFL 86.94 VOLDFL 5002.83 ADJDML 97.60 VOLDML 5005.59 ADJDBL 16.09 VOLDBL 694.79 ADJDR 78.34 VOLDR 11493.94 DENDR 1.02 WADBR 849.13 CAWADR 11624.39 DIFDR 103.95 ADJDSR 5.64 VOLDSR 595.64 ADJDFR 43.20 VOLDFR 5180.50 ADJDMR 47.58 VOLDMR 5069.88 ADJDBR 7.53 VOLDBR 646.83 ADJKL 21.73 VOLKL 3053.22 DENKL 1.07 WAKBL 578.65 CAWAKL 3191.90 DIFKL 60.43 ADJKSL 3.67 VOLKSL 179.16 ADJKFL 17.86 VOLKFL 1009.16 ADJKML 28.15 VOLKML 1430.65 ADJKBL 10.75 VOLKBL 456.25 ADJKR 22.97 VOLKR 3229.57 DENKR 1.06 WAKBR 599.30 CAWAKR 3381.00 DIFKR 57.97 ADJKSR 4.04 VOLKSR 223.14 ADJKFR 17.18 VOLKFR 1069.48 ADJKMR 26.64 VOLKMR 1495.54 ADJKBR 10.10 VOLKBR 421.10

DATA for CASE NUMBER 5

SEQNUM 5. SUBFILE SS.D CASWGT 1.0000 SUBNUM 7.00 SEX 2.00 DOB 3.00 DODEM 83.00 AGEATDEM 79.00 DOANTHR 30483.00 DODISS 2583.00

LTOTHANG 151.50 LTOTSUS 151.50 LTOTSUP 149.90 WATBBWW 49100.00 WATBAWW 49150.00 WALUNH2O 50.00 WWCADCF 6100.00 WWCF 6300.00 WWCAD -200.00 WATBBDI 49000.00 HGFHD 53.90 HGNAS 53.80 HGMAND 41.00 HLVERTRA 11.30 HLVERMEN 19.40 HLVERMAS 14.60 HLINC7 13.70 HBBITRA 13.10 HBBIZY 11.20 HDINGLAB 17.80 WAHEAD 3481.82 WWHEAD 266.00 SFHSUBL 15.40 SFSSUBL 13.50 TSFHAXL 26.50 TSFHXIL 13.30 TSFHICL 17.70 TSFHSSL 13.80 TSFHABL 17.10 TSFSAXL 20.10 TSFSXIL 14.00 TSFSICL 16.10 TSFSSSL 9.80 TSFSABL 12.70 TGAX 82.60 TGMESOST 84.20 TGTHBF 75.90 TGXIPH 76.40 TGWAI 75.60 TGHIP 86.30 TLC7CO 54.30 TBBIAC 30.30 TBMESOST 25.70 TBXIPH 23.30 TBBIILCR 27.40 TBBITROC 30.00 DAPCHMES 18.20 DAPCHXI 18.40 DBUTT 19.10 NGSUPTHY 32.70 NGINFTHY 31.00 WATR 21218.86 WWTR&C&F 5355.00 WWC&F 6355.00 WWTR -1000.00 SFHSUBR 14.30 SFSSUBR 10.50 TSFHAXR 11.80 TSFHXIR 16.80 TSFHICR 15.10 TSFHSSR 12.80 TSFHABR 14.60 TSFSAXR 8.30 TSFSXIR 14.00 TSFSICR 13.70 TSFSSSR 9.70 TSFSABR 11.50 SFHTRL 33.60 SFHBIL 15.60 SFSTRL 26.80 SFSBIL 14.40 GAXARML 27.60 GTRL 27.00 GELL 24.50 GMNARML 26.20 LACRADL 28.40 BEPIHUL 6.30 WABATOTL 1508.29 WWBATOTL 32.40 LBGBAAXL 15.30 LBGBATRL 14.30 LBGBAEPL 16.80 LBBBAEPL 5.80 LBGBAPRL 14.40 WABASL 95.20 WWBASL 4.90 WABAFL 758.74 WWBAFL -38.90 WABAML 481.48 WWBAML 26.30 WABABL 172.88 WWBABL 29.70 SFHTRR 26.00 SFHBIR 10.10 SFSTRR 21.40 SFSBIR 8.20 GAXARMR 26.30 GTRR 26.30 GELR 21.00 GMNARMR 23.40 LACRADR 30.10 BEPIHUR 5.71 WABATOTR 1390.46 WWBATOTR 21.30 WABASR 94.63 WWBASR 3.20 WABAFR 679.27 WWBAFR -42.90 WABAMR 445.06 WWBAMR 20.50 WABABR 171.50 WWBABR 28.50 SFHMXFL 11.90 SFHMDFL 11.70 SFSMXFL 12.20 SFSMDFL 11.30

GMXFL 23.40 GMDFL 20.30 GPRSTYL 16.20 GBISTYL 15.60 GDISTYL 15.20 LOLSTYL 22.20 BBISTYL 4.97 WAVATOTL 732.04 WWVATOTL 43.80 WAVASL 67.18 WWVASL 1.20 WAVAFL 262.25 WWVAFL -8.00 WAVAML 307.81 WWVAML 18.70 WAVABRL 40.00 WWVABRL 9.10 WAVABUL 45.10 WWVABUL 11.00 SFHMXFR 8.60 SFHMDFR 6.80 SFSMXFR 5.50 SFSMDFR 5.40 GMXFR 22.00 GMDFR 16.50 GPRSTYR 13.90 GBISTYR 14.00 GDISTYR 13.10 LOLSTYR 22.80 BBISTYR 4.92 WAVATOTR 547.28 WWVATOTR 32.30 WAVASR 31.46 WWVASR 2.00 WAVAFR 147.42 WWVAFR -10.40 WAVAMR 278.38 WWVAMR 15.20 WAVABRR 40.50 WWVABRR 9.40 WAVABUR 45.90 WWVABUR 11.30 SFHHL 4.50 SFSHL 2.50 GMETACL 16.80 GPHAL3L 5.40 LSTYMETL 6.40 LSTYDACL 15.80 BMETACL 6.66 DMETACL 2.29 WAHATOTL 300.16 WWHATOTL 24.70 WAHSL 67.67 WWHSL 3.20 WAHFL 61.87 WWHFL -0.50 WAHML 93.27 WWHML 5.20 WAHBL 77.34 WWHBL 10.70 SFHHR 1.60 SFSHR 1.20 GMETACR 16.50 GPHAL3R 5.40 LSTYMETR 6.30 LSTYDACR 15.70 BMETACR 6.65 DMETACR 1.95 WAHATOTR 241.04 WWHATOTR 21.20 WAHSR 51.75 WWHSR 2.40 WAHFR 44.62 WWHFR -0.50 WAHMR 68.82 WWHMR 4.50 WAHBR 75.85 WWHBR 10.60 SFHANTTL 19.30 SFHMEDTL 34.10 SFHPOSTL 37.80 SFHSUPPL 20.60 SFSANTTL 15.50 SFSMEDTL 30.10 SFSPOSTL 36.20 SFSSUPPL 19.10 GUPTHL 45.70 GMDTHL 40.20 GSUPPATL 37.60 GMIDPATL 36.50 LTROTIBL 34.30 BEPIFEL 9.65 WADTOTL 7260.55 WWDTOTL -22.00 WADSL 442.94 WWDSL 13.60 WADFL 4190.09 WWDFL -249.10 WADML 2128.39 WWDML 77.60 WADBFL 464.60 WWDBFL 83.00 WADBPL 15.90 WWDBPL 1.90 SFHANTTR 17.50 SFHMEDTR 40.80 SFHPOSTR 43.80 SFHSUPPR 20.70 SFSANTTR 15.10 SFSMEDTR 33.90 SFSPOSTR 39.10 SFSSUPPR 22.30 GUPTHR 44.10 GMDTHR 41.30 GSUPPATR 38.30 GMDPATR 38.00 LTROTIBR 33.10 BEPIFER 9.76 WADTOTR 7290.97

WWDTOTR -12.60 WADSR 394.07 WWDSR 22.10 WADFR 4300.75 WWDFR -268.70 WADMR 2100.55 WWDMR 76.10 WADBFR 460.70 WWDBFR 79.00 WADBPR 16.70 WWDBPR 2.20 SFHMEDCL 24.60 SFSMEDCL 30.10 GINFPATL 30.30 GMXCAL 30.50 GMNANKL 18.80 GBIMALL 22.90 GMDLEGL 24.60 LTIBMALL 34.20 BCONTIL 8.29 BBIMALL 6.40 WAKTOTL 1809.76 WWKTOTL 78.20 WAKSL 100.57 WWKSL 6.00 WAKFL 672.94 WWKFL -37.70 WAKML 694.17 WWKML 29.50 WAKBTL 288.50 WWKBTL 46.80 WAKBFL 43.50 WWKBFL 9.80 SFHMEDCR 25.60 SFSMEDCR 14.60 GINFPATR 32.10 GMXCAR 31.70 GMNANKR 19.10 GBIMALR 24.00 GMDLEGR 24.50 LTIBMALR 36.00 BCONTIR 10.30 BBIMALR 6.40 WAKTOTR 1895.86 WWKTOTR 78.20 WAKSR 107.57 WWKSR 4.00 WAKFR 784.37 WWKFR -27.30 WAKMR 642.97 WWKMR 28.50 WAKBTR 282.00 WWKBTR 41.50 WAKBFR 45.50 WWKBFR 9.20 SFHFL 3.30 SFSFL 2.30 GMETATL 19.60 GPHAL1L 7.00 GARCL 23.00 LMALBALL 6.80 LAKPTEL 21.00 BHEELL 5.21 BMETATL 7.45 DMETATL 1.84 WAVTOTL 656.00 WWVTOTL 32.40 WAVSL 94.10 WWVSL 5.30 WAVFL 206.00 WWVFL -0.90 WAVML 145.20 WWVML 5.00 WAVBL 180.00 WWVBL 17.30 SFHFR 2.90 SFSFR 2.10 GMETATR 19.90 GPHAL1R 7.00 GARCR 21.60 LMALBALR 6.80 LAKPTER 20.30 BHEELR 5.31 BMETATR 7.32 DMETATR 2.05 WAVTOTR 648.60 WWVTOTR 28.80 WAVSR 79.20 WWVSR 5.40 WAVFR 230.00 WWVFR -3.60 WAVMR 114.90 WWVMR 4.30 WAVBR 175.20 WWVBR 13.80 WWGA&WT 89.70 WAFLBUPF 903.40 WABUPF 639.50 WAFLPF 263.90 WAFLBUPS 795.00 WABUPS 632.30 WAFLPS 162.70 X 1.60 VOLTOT 49200.00 CAWATOTB 48321.39 DIFTOT 678.61 ADJHEAD 48.22 VOLHEAD 3215.82 CDENHEAD 1.08 ADJTR 293.87 VOLTR 22218.86 CDENTR 0.95 ADJBAL 20.89 VOLBAL 1475.89 CDENBAL 1.02 CAWABAL 1429.10 DIFBAL 79.19 ADJBASL 5.00 VOLBASL 90.30 ADJBAFL 39.84 VOLBAFL 797.64 ADJBAML

25.28 VOLBAML 455.18 ADJBABL 9.08 VOLBABL 143.18 ADJBAR 19.26 VOLBAR 1369.16 CDENBAR 1.02 CAWABAR 1345.90 DIFBAR 44.56 ADJBASR 3.03 VOLBASR 91.43 ADJBAFR 21.77 VOLBAFR 722.17 ADJBAMR 14.26 VOLBAMR 424.56 ADJBABR 5.50 VOLBABR 143.00 ADJVAL 10.14 VOLVAL 688.24 DENVAL 1.06 WAVABL 94.81 CAWAVAL 657.10 DIFVAL 74.94 ADJVASL 6.88 VOLVASL 65.98 ADJVAFL 26.85 VOLVAFL 270.25 ADJVAML 31.51 VOLVAML 289.11 ADJVABL 9.71 VOLVABL 74.71 ADJVAR 7.58 VOLVAR 514.98 DENVAR 1.06 WAVABR 90.02 CAWAVAR 525.30 DIFVAR 21.98 ADJVASR 1.26 VOLVASR 29.46 ADJVAFR 5.92 VOLVAFR 157.82 ADJVAMR 11.18 VOLVAMR 263.18 ADJVABR 3.62 VOLVABR 34.72 ADJHAL 4.16 VOLHAL 275.46 CDENHAL 1.09 CAWAHAL 263.90 DIFHAL 36.26 ADJHASL 8.17 VOLHASL 64.47 ADJHAFL 7.47 VOLHAFL 62.37 ADJHAML 11.27 VOLHAML 88.07 ADJHABL 9.34 VOLHABL 66.64 ADJHAR 3.34 VOLHAR 219.84 CDENHAR 1.10 CAWAHAR 216.10 DIFHAR 24.94 ADJHASR 5.35 VOLHASR 49.35 ADJHAFR 4.62 VOLHAFR 45.12 ADJHAMR 7.12 VOLHAMR 64.32 ADJHABR 7.85 VOLHABR 65.25 ADJDL 100.55 VOLDL 7282.55 DENDL 1.00 WADBL 499.14 CAWADL 6989.39 DIFDL 271.16 ADJDSL 16.54 VOLDSL 429.34 ADJDFL 156.49 VOLDFL 4439.18 ADJDML 79.49 VOLDML 2050.79 ADJDBL 18.64 VOLDBL 414.24 ADJDR 100.97 VOLDR 7303.57 DENDR 1.00 WADBR 495.60 CAWADR 7023.19 DIFDR 267.78 ADJDSR 14.47 VOLDSR 371.97 ADJDFR 157.96 VOLDFR 4569.45 ADJDMR 77.15 VOLDMR 2024.45 ADJDBR 18.20 VOLDBR 399.90 ADJKL 25.06 VOLKL 1731.56 DENKL 1.05 WAKBL 342.09 CAWAKL 1756.40 DIFKL 53.36 ADJKSL 2.97 VOLKSL 94.57 ADJKFL 19.84 VOLKFL 710.64 ADJKML 20.47 VOLKML 664.67 ADJKBL 10.09 VOLKBL 285.49 ADJKR 26.26 VOLKR 1817.66 DENKR 1.04 WAKBR 360.94 CAWAKR 1720.20 DIFKR 175.66

ADJKSR 9.97 VOLKSR 103.57 ADJKFR 72.67 VOLKFR 811.67 ADJKMR 59.57 VOLKMR 614.47 ADJKBR 33.44 VOLKBR 273.94

DATA for CASE NUMBER 6

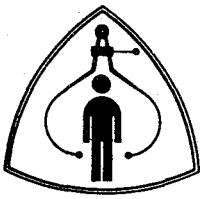
SEQNUM 6. SUBFILE SS.D CASWGT 1.0000 SUBNUM 113.00 SEX 2.00 DOB 2.00 DODEM 81.00 AGEATDEM 79.00 DOANTHR 3583.00 DODISS 4583.00 LTOTHANG 165.00 LTOTSUS 165.00 LTOTSUP 162.00 WATBBWW 55700.00 WATBAWW 55900.00 WALUNH2O 200.00 WWCADCF 7615.00 WWCF 6355.00 WWCAD 1260.00 WATBBDI 55750.00 HGFHD 55.40 HGNAS 56.00 HGMAND 44.00 HLVERTRA 12.10 HLVERMEN 22.50 HLVERMAS 16.10 HLINC7 13.30 HBBITRA 14.70 HBBIZY 13.40 HDINGLAB 17.80 WAHEAD 4329.48 WWHEAD 287.60 SFHSUBL 14.00 SFSSUBL 13.40 TSFHAXL 9.60 TSFHXIL 13.20 TSFHICL 11.70 TSFHSSL 7.80 TSFHABL 7.30 TSFSAXL 6.80 TSFSXIL 15.50 TSFSICL 12.90 TSFSSSL 7.50 TSFSABL 8.70 TGAX 89.50 TGMESOST 89.10 TGTHBF 79.00 TGXIPH 79.00 TGWAI 73.20 TGHIP 92.50 TLC7CO 56.90 TBBIAC 36.00 TBMESOST 27.70 TBXIPH 24.70 TBBIILCR 31.50 TBBITROC 34.10 DAPCHMES 17.60 DAPCHXI 16.60 DBUTT 18.70 NGSUPTHY 31.60 NGINFTHY 33.20 WATR 25083.55 WWTR&C&F 6585.00 WWC&F 6553.00 WWTR 32.00 SFHSUBR 22.00 SFSSUBR 18.50 TSFHAXR 11.50 TSFHXIR 15.70 TSFHICR 16.70 TSFHSSR 10.40 TSFHABR 8.20 TSFSAXR 10.80 TSFSXIR 14.10 TSFSICR 11.40 TSFSSSR 7.40 TSFSABR 6.50 SFHTRL 20.90 SFHBIL 9.10 SFSTRL 18.30 SFSBIL 9.90 GAXARML 27.30 GTRL 24.00 GELL 21.50 GMNARML 21.60 LACRADL 34.20 BEPIHUL 6.71 WABATOTL 1449.43 WWBATOTL 39.90 LBGBAAXL 0.0 LBGBATRL 0.0 LBGBAEPL 0.0 LBBBAEPL 0.0 LBGBAPRL 0.0 WABASL 92.20 WWBASL 5.30 WABAFL 629.20 WWBAFL -29.10 WABAML 536.80 WWBAML 26.30 WABABL

191.23 WWBABL 134.60 SFHTRR 26.80 SFHBIR 11.20 SFSTRR 22.50 SFSBIR 10.50 GAXARMR 25.00 GTRR 24.30 GELR 21.70 GMNARMR 21.40 LACRADR 34.10 BEPIHUR 5.91 WABATOTR 1544.11 WWBATOTR 41.00 WABASR 95.97 WWBASR 6.10 WABAFR 652.50 WWBAFR -33.90 WABAMR 596.70 WWBAMR 26.70 WABABR 198.94 WWBABR 35.60 SFHMXFL 11.10 SFHMDFL 8.50 SFSMXFL 10.70 SFSMDFL 3.40 GMXFL 21.20 GMDFL 16.50 GPRSTYL 14.30 GBISTYL 14.80 GDISTYL 14.70 LOLSTYL 26.20 BBISTYL 5.10 WAVATOTL 616.36 WWVATOTL 46.00 WAVASL 59.11 WWVASL 3.40 WAVAFL 135.25 WWVAFL -2.80 WAVAML 311.70 WWVAML 16.00 WAVABRL 46.80 WWVABRL 11.20 WAVABUL 54.90 WWVABUL 14.70 SFHMXFR 14.80 SFHMDFR 6.60 SFSMXFR 11.40 SFSMDFR 6.40 GMXFR 21.60 GMDFR 17.00 GPRSTYR 14.30 GBISTYR 14.70 GDISTYR 14.60 LOLSTYR 26.30 BBISTYR 5.18 WAVATOTR 721.20 WWVATOTR 53.00 WAVASR 70.42 WWVASR 2.60 WAVAFR 152.71 WWVAFR -3.60 WAVAMR 381.71 WWVAMR 18.10 WAVABRR 46.60 WWVABRR 12.20 WAVABUR 60.30 WWVABUR 16.40 SFHHL 2.50 SFSHL 2.20 GMETACL 17.90 GPHAL3L 5.90 LSTYMETL 7.10 LSTYDACL 17.00 BMETACL 7.06 DMETACL 2.57 WAHATOTL 341.95 WWHATOTL 27.10 WAHSL 55.42 WWHSL 4.10 WAHFL 106.73 WWHFL 0.40 WAHML 100.84 WWHML 5.70 WAHBL 78.96 WWHBL 13.00 SFHHR 1.50 SFSHR 1.50 GMETACR 17.40 GPHAL3R 5.60 LSTYMETR 7.40 LSTYDACR 17.50 BMETACR 7.04 DMETACR 2.21 WAHATOTR 306.37 WWHATOTR 28.60 WAHSR 59.95 WWHSR 4.70 WAHFR 93.34 WWHFR 1.70 WAHMR 69.77 WWHMR 4.50 WAHBR 83.31 WWHBR 15.60 SFHANTTL 20.90 SFHMEDTL 31.20 SFHPOSTL 31.90 SFHSUPPL 20.50 SFSANTTL 18.50 SFSMEDTL 29.20 SFSPOSTL 26.40 SFSSUPPL 22.10 GUPTHL 43.60 GMDTHL 35.70 GSUPPATL 33.40 GMIDPATL 34.90 LTROTIBL 44.50 BEPIFEL 9.50 WADTOTL 8031.16 WWDTOTL 95.40 WADSL 452.64

WWDSL 22.90 WADFL 3880.44 WWDFL -172.80 WADML 3017.08 WWDML 86.20 WADBFL 612.10 WWDBFL 126.80 WADBPL 23.10 WWDBPL 4.80 SFHANTTR 20.50 SFHMEDTR 31.60 SFHPOSTR 33.20 SFHSUPPR 22.50 SFSANTTR 17.70 SFSMEDTR 24.80 SFSPOSTR 27.20 SFSSUPPR 15.70 GUPTHR 45.00 GMDTHR 37.30 GSUPPATR 34.60 GMDPATR 35.20 LTROTIBR 43.60 BEPIFER 8.94 WADTOTR 7659.25 WWDTOTR 85.70 WADSR 447.93 WWDSR 25.00 WADFR 3716.43 WWDFR -171.00 WADMR 2847.16 WWDMR 27.80 WADBFR 590.50 WWDBFR 118.60 WADBPR 23.50 WWDBPR 4.60 SFHMEDCL 26.20 SFSMEDCL 20.10 GINFPATL 30.40 GMXCAL 29.80 GMNANKL 21.00 GBIMALL 26.20 GMDLEGL 26.30 LTIBMALL 38.10 BCONTIL 8.88 BBIMALL 6.43 WAKTOTL 2224.30 WWKTOTL 95.80 WAKSL 131.77 WWKSL 3.40 WAKFL 833.83 WWKFL -26.10 WAKML 803.81 WWKML 24.70 WAKBTL 337.90 WWKBTL 62.90 WAKBFL 51.50 WWKBFL 11.20 SFHMEDCR 24.40 SFSMEDCR 18.10 GINFPATR 30.80 GMXCAR 30.00 GMNANKR 18.50 GBIMALR 24.10 GMDLEGR 23.90 LTIBMALR 37.60 BCONTIR 9.04 BBIMALR 6.47 WAKTOTR 1933.41 WWKTOTR 97.10 WAKSR 92.69 WWKSR 4.60 WAKFR 750.85 WWKFR -33.20 WAKMR 671.52 WWKMR 28.20 WAKBTR 327.80 WWKBTR 60.90 WAKBFR 63.50 WWKBFR 16.70 SFHFL 5.00 SFSFL 3.50 GMETATL 21.70 GPHAL1L 6.90 GARCL 24.50 LMALBALL 6.60 LAKPTEL 22.80 BHEELL 6.16 BMETATL 8.35 DMETATL 2.47 WAVTOTL 775.40 WWVTOTL 40.30 WAVSL 88.90 WWVSL 5.70 WAVFL 269.20 WWVFL -1.60 WAVML 144.70 WWVML 5.00 WAVBL 202.30 WWVBL 26.70 SFHFR 4.90 SFSFR 3.40 GMETATR 22.10 GPHAL1R 7.70 GARCR 24.40 LMALBALR 6.40 LAKPTER 22.20 BHEELR 5.76 BMETATR 8.71 DMETATR 2.95 WAVTOTR 726.30 WWVTOTR 42.30 WAVSR 104.20 WWVSR 7.30 WAVFR 204.20 WWVFR -4.00 WAVMR 178.30 WWVMR 7.30 WAVBR 205.20 WWVBR 27.30 WWGA&WT

89.20 WAFLBUPF 1601.00 WABUPF 721.40 WAFLPF 879.60 WAFLBUPS 0.0 WABUPS 0.0 WAFLPS 0.0 X 3.00 VOLTOT 54490.00 CAWATOTB 55464.29 DIFTOT 285.71 ADJHEAD 22.19 VOLHEAD 4041.89 CDENHEAD 1.07 ADJTR 128.55 VOLTR 25051.55 CDENTR 1.00 ADJBAL 7.43 VOLBAL 1409.53 CDENBAL 1.03 CAWABAL 1422.70 DIFBAL 26.73 ADJBASL 1.70 VOLBASL 86.90 ADJBAFL 11.60 VOLBAFL 658.30 ADJBAML 9.90 VOLBAML 510.50 ADJBABL 3.53 VOLBABL 156.63 ADJBAR 7.91 VOLBAR 1503.11 CDENBAR 1.03 CAWABAR 1502.70 DIFBAR 41.41 ADJBASR 2.57 VOLBASR 89.87 ADJBAFR 17.50 VOLBAFR 686.40 ADJBAMR 16.00 VOLBAMR 570.00 ADJBABR 5.34 VOLBABR 163.34 ADJVAL 3.16 VOLVAL 570.36 DENVAL 1.08 WAVABL 110.30 CAWAVAL 568.30 DIFVAL 48.06 ADJVASL 4.61 VOLVASL 55.71 ADJVAFL 10.55 VOLVAFL 138.05 ADJVAML 24.30 VOLVAML 295.70 ADJVABL 8.60 VOLVABL 84.40 ADJVAR 3.70 VOLVAR 668.20 DENVAR 1.08 WAVABR 116.35 CAWAVAR 662.60 DIFVAR 58.60 ADJVASR 5.72 VOLVASR 67.82 ADJVAFR 12.41 VOLVAFR 156.31 ADJVAMR 31.01 VOLVAMR 363.61 ADJVABR 9.45 VOLVABR 43.85 ADJHAL 1.75 VOLHAL 314.85 CDENHAL 1.09 CAWAHAL 307.90 DIFHAL 34.05 ADJHASL 5.52 VOLHASL 51.32 ADJHAFL 10.63 VOLHAFL 106.33 ADJHAML 10.04 VOLHAML 95.14 ADJHABL 7.86 VOLHABL 65.96 ADJHAR 1.57 VOLHAR 277.77 CDENHAR 1.10 CAWAHAR 287.20 DIFHAR 19.17 ADJHASR 3.75 VOLHASR 55.25 ADJHAFR 5.84 VOLHAFR 91.64 ADJHAMR 4.37 VOLHAMR 65.27 ADJHABR 5.21 VOLHABR 67.71 ADJDL 41.16 VOLDL 7935.75 DENDL 1.01 WADBL 680.99 CAWADL 7491.10 DIFDL 540.06 ADJDSL 30.44 VOLDSL 429.74 ADJDFL 260.94 VOLDFL 4053.24 ADJDML 202.89 VOLDML 2930.88 ADJDBL 45.79 VOLDBL 549.39 ADJDR 39.25 VOLDR 7573.55 DENDR 1.01 WADBR 647.73 CAWADR 7260.40 DIFDR 398.85 ADJDSR 23.33 VOLDSR

422.93 ADJDFR 193.53 VOLDFR 3887.43 ADJDMR 148.26 VOLDMR 2819.36 ADJDBR 33.73 VOLDBR 505.63 ADJKL 11.40 VOLKL 2128.50 DENKL 1.05 WAKBL 454.88 CAWAKL 1904.10 DIFKL 320.20 ADJKSL 18.97 VOLKSL 128.37 ADJKFL 120.03 VOLKFL 859.93 ADJKML 115.71 VOLKML 779.11 ADJKBL 65.48 VOLKBL 380.78 ADJKR 9.91 VOLKR 1836.31 DENKR 1.05 WAKBR 418.35 CAWAKR 1808.40 DIFKR 125.01 ADJKSR 5.99 VOLKSR 88.09 ADJKFR 48.55 VOLKFR 784.05 ADJKMR 43.42 VOLKMR 643.32 ADJKBR 27.05 VOLKBR 293.95



BASIC ANTHROPOMETRIC PROFORMA

Kinanthropometric Research Associates
Department of Kinesiology
Simon Fraser University

A

01. Subject _____ (Last Name) (Given Name) — 1
02. Card Number — 6 | 1
03. Identity — 7 Sex f =2 m=1, — 8 checker number — 7

B

04. Date of observations — Year mo. day — 9
05. Date of birth — Year mo. day — 14
06. Measurement sequence no. — 19
07. Body mass — 20
08. Stature (stretched) — 24

C

09. Triceps sf _____ — 28
10. Subscapular sf _____ — 31
11. Biceps sf _____ — 34
12. Iliac crest sf _____ — 37
13. Supraspinale sf _____ — 40
14. Abdominal sf _____ — 43
15. Front thigh sf _____ — 46
16. Medial calf sf — 49

D

17. Acromial height _____ — 52
18. Radial height _____ — 56
19. Stylion height _____ — 60
20. Dactylion height _____ — 64
21. Spinale height _____ — 68
22. Trochanterion height _____ — 72
23. Tibiale (laterale) height — 76

24. Subject _____ — 1
25. Card Number — 6 | 2

E

26. Arm girth relaxed _____ — 7
27. Arm girth flexed and tensed _____ — 10
28. Forearm girth (max. relaxed) _____ — 13
29. Wrist girth (distal styloid) _____ — 16
30. Chest girth (mesosternale) _____ — 19
31. Waist girth (min.) _____ — 23
32. Gluteal girth (max.) _____ — 27
33. Thigh girth (1 cm dist. glut.line) — 31
34. Calf girth (max) _____ — 34
35. Ankle girth — 37

F

36. Biacromial breadth _____ — 40
37. Biiliocristal breadth _____ — 43
38. Transverse chest breadth _____ — 46
39. Foot length (ak–pte) _____ — 49
40. Humerus width _____ — 52
41. Femur width — 56

G

42. Sitting height _____ — 60
43. Anterior-posterior chest depth _____ — 64
44. Head girth _____ — 67
45. Neck girth _____ — 70

APPENDIX 7 - PHANTOM P AND S VALUES FOR ANTHROPOMETRIC VARIABLES USED IN THE MODEL

	p	s
Forehead girth	56.0	1.44
Mesosternale girth	87.86	5.18
Trunk length	59.97	3.7
Biiliocristal breadth	28.84	1.75
Waist girth	71.91	4.45
Abdominal skinfold	25.4	7.78
Relaxed arm girth	26.89	2.33
Epicondylar humerus breadth	6.48	0.35
Acromiale-radiale length	32.53	1.77
Triceps skinfold	15.4	4.47
Forearm girth	25.13	1.41
Wrist girth	16.38	0.72
Radiale-stylion length	24.57	1.37
Stylion-dactylion length	18.85	0.85
Thigh girth	55.82	4.32
Epicondylar femur breadth	9.52	0.48
Thigh length	35.44	2.12
Thigh skinfold	27.04	8.33
Calf girth	35.25	2.30
Tibiale height	44.82	2.56
Ankle girth	21.71	1.33
Medial calf skinfold	16.01	4.67
Foot length skinfold	25.5	1.16

where: Skinfolds are in millimeters.
All lengths, breadths, girths and heights are in centimeters.

APPENDIX 8 - CALCULATION OF SEGMENT WEIGHTS AS PERCENTAGES OF TOTAL BODY WEIGHT.

MiniCAS Data Analysis

	WATBBDI	PERHEAD	PERTRUNK	PERARM	PERFARM
1	43600.0	8.5	46.4	2.4	1.4
2	66300.0	6.8	50.5	2.5	1.3
3	50900.0	7.3	47.7	2.9	1.3
4	80100.0	6.5	44.1	2.8	1.4
5	49000.0	7.1	43.3	3.0	1.3
6	55750.0	7.8	45.0	2.7	1.2
M	57608.3	7.32	46.16	2.71	1.33
S	13418.0	0.72	2.63	0.22	0.08
M	43600.0	6.5	43.3	2.4	1.2
M	80100.0	8.5	50.5	3.0	1.4

	PERHAND	PERTHIGH	PERLEG	PERFOOT
1	1.0	11.2	4.0	2.5
2	0.5	12.5	3.3	1.2
3	0.5	13.4	3.1	1.3
4	0.6	14.4	4.2	1.3
5	0.6	14.8	3.8	1.3
6	0.6	14.1	3.7	1.4
M	0.62	13.41	3.69	1.51
S	0.19	1.37	0.41	0.49
M	0.5	11.2	3.1	1.2
M	1.0	14.8	4.2	2.5

CLAUSER Data Analysis

	WATBBDI	PERHEAD	PERTRUNK	PERARM	PERFARM
1	67152.0	7.6	46.4	3.0	1.6
2	54000.0	8.1	47.8	2.7	1.9
3	60490.0	7.3	49.5	2.5	1.4
4	87865.0	5.9	51.6	2.6	1.5
5	76140.0	6.4	49.0	2.7	1.8
6	69850.0	7.6	51.6	2.7	1.4
7	66400.0	7.4	52.0	2.2	1.5
8	74320.0	6.5	50.5	2.6	1.3
9	65798.0	7.3	52.7	2.4	1.7
10	58588.0	7.4	48.8	2.4	1.5
11	62428.0	7.0	52.2	2.9	1.7
12	57326.0	7.6	48.7	2.4	1.6
13	64375.0	7.2	49.2	2.8	1.7
M	66517.9	7.18	49.99	2.60	1.59
S	9050.4	0.60	1.94	0.23	0.16
M	54000.0	5.9	46.4	2.2	1.3
M	87865.0	8.1	52.7	3.0	1.9

	PERHAND	PERTHIGH	PERLEG	PERFOOT
1	0.6	11.0	4.9	1.5
2	0.6	10.7	3.9	1.4
3	0.7	9.9	5.0	1.6
4	0.6	10.7	3.9	1.2
5	0.7	10.4	4.4	1.5
6	0.6	9.5	4.1	1.4
7	0.5	8.9	4.3	1.4
8	0.5	11.3	3.9	1.4
9	0.8	8.7	4.2	1.4
10	0.6	10.8	4.2	1.6
11	0.8	8.7	3.9	1.4
12	0.7	10.4	4.7	1.6
13	0.7	10.6	4.2	1.4
M	0.64	10.13	4.29	1.45
S	0.08	0.88	0.38	0.12
M	0.5	8.7	3.9	1.2
M	0.8	11.3	5.0	1.6

SUMMARY COMPARISON: MEAN PERCENTAGES.

	WATBBDI	PERHEAD	PERTRUNK	PERARM	PERFARM
MCAS:	57608.3	7.32	46.16	2.71	1.33
CL:	66517.9	7.18	49.99	2.60	1.59
		PERHAND	PERTHIGH	PERLEG	PERFOOT
MCAS:		0.62	13.41	3.69	1.51
CL:		0.64	10.13	4.29	1.45

APPENDIX 9 - APPLICATION OF MCREG TO CAS SAMPLE

CAS Data Analysis
MCREGCAS applies mcreg to the CAS data,
predicting segment masses,
summing limb segments and comparing
these to observed values.

	WATBBDI	PRTOT	PDISCREP
Mean	64195.7	60675.3	-5.3717
S.D.	11356.3	8349.76	6.6101
Minima	48200.0	47334.3	-22.14
Maxima	88900.1	74630.6	6.76

	PDHDTR	PDUL	PDLL	PDUL(BARTER)*
1	12.38	26.22	-4.94	1.418*
2	-9.06	-11.52	-7.08	6.57*
3	-3.62	-8.71	-12.29	6.99*
4	1.14	-12.76	-2.71	10.34*
5	-1.38	-5.81	1.90	-0.95*
6	2.41	-7.43	5.26	1.04*
7	6.83	-2.90	-1.03	-3.54*
8	4.18	-1.38	-11.69	17.45*
9	-14.22	-3.04	-9.90	14.39*
10	-4.36	-5.69	-9.70	1.07*
11	999999	-1.26	-7.15	13.96*
12	-.86	-6.87	-2.16	9.32*
13	999999	-9.10	1.34	-3.82*
14	-5.65	-2.86	-12.30	30.89*
15	-2.68	-2.41	-.43	13.65*
16	-8.28	-8.23	-18.91	16.83*
17	-6.05	-6.54	-2.11	11.14*
18	6.82	-6.72	-11.91	8.63*
19	-13.50	-.35	-11.24	32.18*
20	4.39	-7.25	-5.60	16.79*
21	-10.04	-14.11	-15.21	12.75*
22	-11.29	-.52	-7.22	25.10*
23	-25.08	-18.21	-19.63	1.54*
M	-3.7108	-5.1067	-7.1610	10.60*
S	8.6715	8.2162	6.5846	9.95*
M	-25.08	-18.21	-19.63	-3.82*
M	12.38	26.22	5.26	32.18*

SUMMARY
Application of MCREG to CAS Data.

	WATBBDI	PRTOT	PDISCREP
Mean	64195.7	60675.3	-5.3717
S.D.	11356.3	8349.76	6.6101
Minima	48200.0	47334.3	-22.14
Maxima	88900.1	74630.6	6.76

	PDHDTR	PDUL	PDLL	PDUL(BARTER)*
M	-3.7108	-5.1067	-7.1610	10.60*
S	8.6715	8.2162	6.5846	9.95*
M	-25.08	-18.21	-19.63	-3.82*
M	12.38	26.22	5.26	32.18*

APPENDIX 10 - APPLICATION OF MC MODELS TO CAS SAMPLE

MCPDCAS ANALYSIS OF CAS SAMPLE

	PDHDTR	PDUL	PDLL
1	999999	999999	999999
2	999999	-10.53	999999
3	999999	-2.74	-16.06
4	999999	-7.18	-20.97
5	999999	-4.09	999999
6	999999	-5.36	-5.41
7	999999	1.78	999999
8	999999	-8.51	-25.76
9	-2.84	1.19	999999
10	-1.18	.57	-15.41
11	999999	-5.97	-17.06
12	-6.15	-3.72	-13.20
13	999999	-4.60	-1.76
14	-12.00	2.82	-13.64
15	4.51	6.43	-8.79
16	-4.37	-2.06	-18.47
17	-13.90	-11.07	-22.34
18	-1.49	-14.62	-25.44
19	-2.19	12.25	-8.42
20	999999	-6.83	-17.61
21	999999	999999	999999
22	-6.96	4.98	-12.07
23	-13.82	-7.17	-12.90
M	-5.4903	-3.0675	-15.019
S	5.8203	6.4353	6.6423
M	-13.90	-14.62	-25.76
M	4.51	12.25	-1.76

MCGXLCAS ANALYSIS OF CAS SAMPLE

	SEQNUM	PDHDTR	PDUL	PDLL
	1	999999	-.05	-6.42
	2	-5.68	-13.44	-13.98
	3	-2.63	-8.37	-20.96
	4	4.83	-8.62	-22.78
	5	999999	-4.33	-4.07
	6	-7.26	-7.72	-6.36
	7	14.76	-8.92	-8.61
	8	8.79	-1.68	-19.72
	9	-6.44	-8.26	-18.23
	10	-2.39	-6.69	-17.26
	11	999999	-6.01	-12.26
	12	3.03	-8.60	-9.21
	13	999999	-14.32	-7.98
	14	-.39	-7.24	-8.06
	15	11.26	-3.89	-9.70
	16	-4.68	-13.06	-19.42
	17	-14.36	-7.40	-12.39
	18	.80	-5.74	-13.85
	19	-4.50	-4.70	-17.10
	20	999999	-7.72	-10.65
	21	999999	-12.98	-13.97
	22	-3.52	-3.13	-10.64
	23	-13.03	-16.87	-20.30
M		-1.2606	-7.8148	-13.215
S		7.8980	4.1537	5.3750
M		-14.36	-16.87	-22.78
M		14.76	-.05	-4.07

MCGALCAS ANALYSIS ON CAS SAMPLE

	SEQNUM	PDHDTR	PDUL	PDLL
	1	999999	1.66	-6.67
	2	-7.02	-11.48	-11.94
	3	-2.25	-6.83	-18.90
	4	1.88	-13.37	-17.53
	5	999999	-7.18	-4.06
	6	-1.98	-7.70	-3.66
	7	11.71	-6.99	-6.08
	8	7.89	.47	-15.20
	9	-9.88	-5.79	-15.23
	10	-3.07	-5.98	-15.22
	11	999999	-3.49	-9.87
	12	.98	-8.55	-6.64
	13	999999	-12.32	-4.51
	14	-3.14	-5.61	-9.90
	15	5.29	-6.75	-7.60
	16	-6.45	-10.18	-18.98
	17	-9.59	-4.37	-6.43
	18	4.29	-4.84	-12.84
	19	-8.38	-4.63	-15.39
	20	999999	-8.70	-8.97
	21	999999	-10.99	-14.25
	22	-7.45	-3.90	-10.55
	23	-17.95	-16.74	-19.02
M		-2.6533	-7.1419	-11.280
S		7.4460	4.2080	5.0637
M		-17.95	-16.74	-19.02
M		11.71	1.66	-3.66

APPENDIX 11 - COMPARISON OF MCPDCO AND MCVOLACO

MODEL=MCPDCO BROKEN DOWN BY SEX BY AGE.
VARIABLE=%DIFF

		MEAN	STD DEV	N
TOTAL POPULATION		2.06	5.38	889
MALES	ALL	3.41	5.34	456
	AGE			
	5	1.03	1.03	2
	6	4.77	7.06	4
	7	2.22	2.99	22
	8	2.37	6.81	22
	9	2.89	3.19	26
	10	4.31	2.12	21
	11	2.31	4.27	25
	12	0.04	8.76	31
	13	3.64	4.05	33
	14	4.08	3.43	75
	15	4.06	5.55	74
	16	3.43	5.14	53
	17	4.32	7.82	43
	18	4.68	4.20	21
	19	3.65	3.73	4
FEMALES	ALL	0.64	5.06	433
	AGE			
	6	0.16	3.43	13
	7	2.43	4.69	25
	8	2.03	4.27	15
	9	2.15	3.09	30
	10	1.50	5.53	19
	11	-0.94	10.09	23
	12	0.62	4.69	35
	13	1.38	5.13	36
	14	1.13	5.83	64
	15	-0.05	4.12	64
	16	-0.04	4.41	51
	17	-0.32	4.02	47
	18	-1.15	2.37	10
	19	2.02	0.0	1

MODEL=MCVOLACO
VARIABLE=%DIFF

	MEAN	STD DEV	N
TOTAL POPULATION	-0.8	7.4	(896)
MALES ALL	-0.9	7.2	(460)
AGE			
5.00	-24.6	4.6	(2)
6.00	-13.8	20.1	(4)
7.00	-12.4	6.9	(22)
8.00	-7.5	8.5	(22)
9.00	-6.5	5.8	(27)
10.00	-0.6	4.6	(21)
11.00	-1.1	4.7	(26)
12.00	-1.4	8.4	(31)
13.00	1.7	3.5	(34)
14.00	1.6	3.3	(75)
15.00	1.6	5.6	(74)
16.00	0.4	4.7	(54)
17.00	1.4	7.5	(43)
18.00	1.2	4.9	(21)
19.00	-0.2	5.3	(4)
FEMALE ALL	-0.7	7.7	(36)
AGE			
6.00	-18.8	9.4	(13)
7.00	-12.6	8.5	(25)
8.00	-11.4	8.0	(14)
9.00	-5.3	8.9	(30)
10.00	-0.1	5.5	(20)
11.00	-2.2	9.8	(23)
12.00	1.0	5.0	(35)
13.00	1.4	3.5	(36)
14.00	2.6	4.4	(65)
15.00	2.2	3.6	(65)
16.00	2.2	4.1	(52)
17.00	1.8	3.1	(47)
18.00	1.6	3.2	(10)
19.00	0.3	0.0	(1)