Ergonomics

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/terg20

Cadaver studies and their impact on the understanding of human adiposity

J. P. Clarys a, S. Provyn a & M. J. Marfell-Jones b

a Experimental Anatomy, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Laarbeeklaan 103, B-Brussels, Belgium
b Universal College of Learning, Private Bag 11022, Palmerston North, New Zealand

Available online: 20 Feb 2007

To cite this article: J. P. Clarys, S. Provyn & M. J. Marfell-Jones (2005): Cadaver studies and their impact on the understanding of human adiposity, Ergonomics, 48:11-14, 1445-1461

To link to this article: http://dx.doi.org/10.1080/00140130500101486

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Cadaver studies and their impact on the understanding of human adiposity

J. P. CLARYS*†, S. PROVYN† and M. J. MARFELL-JONES‡

†Experimental Anatomy, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Laarbeeklaan 103, B-Brussels, Belgium
‡Universal College of Learning, Private Bag 11022, Palmerston North, New Zealand

The skinfold thickness is a much-used measurement for monitoring adiposity in a wide range of medical, health, occupational and sport science disciplines. Misconceptions abound, however, in its use, particularly that of purportedly predicting body ‘fat’ as opposed to ‘adipose tissue’. To obtain data to investigate body composition and the extent to which anthropometry can be justifiably used to predict whole-body adiposity, an extensive dissection study was undertaken on 34 cadavers. In addition, to pre-empt questions on the applicability of cadaver data to living subjects, 40 elderly in vivo subjects of the same age range were compared with the cadaver population. No significant macro-morphological differences were found between males or females in the morbid and in vivo groups. Significant findings affect our previous understanding of the predictability of whole-body ‘fat’. Skinfold compressibility was by no means constant; skin thickness varied with location in both sexes, females having thinner skin than males; there were significant sex differences in adipose tissue patterning. An identical thickness of adipose tissue did not necessarily contain the same concentrations of fat. Despite this variability, a relationship was demonstrated between aggregate skinfold measures and subcutaneous adipose tissue mass (as opposed to subcutaneous fat), this relationship being more evident in men. A strong relationship was found between subcutaneous adiposity and whole-body adiposity, and between direct skinfold depth measures and whole-body adiposity. The amount of visceral adipose tissue was the same in men and women, but in the men this represented a greater proportion of their total body adiposity. Further, the use of waist-to-hip girth ratio (WHR) was identified as an important predictor of health risk. These findings demonstrate that it is not sustainable to introduce a non-quantifiable error by transforming anthropometric values (skinfolds) into predictions of percentage body fat. If subcutaneous adiposity can be predicted, then an excellent indication of overall adiposity could be obtained. Currently, skinfold measurement can yield a reasonable indication of comparative subcutaneous adiposity (better in men than in women). In

*Corresponding author. Email: jclarys@exan.vub.ac.be
neither gender is this prediction completely reliable due to both inter- and intra-individual differences in the skinfold measurement procedure.

Keywords: Body fat; Skinfold compressibility; Skinfold measurement; Subcutaneous adipose tissue; Whole-body adipose tissue; Waist–hip ratio; BMI and gender

1. Introduction

Methods for assessing human body composition are applied in many fields. In particular, the assessment or prediction of ‘total body fat’ is a common, popular and, at the same time, important ingredient of public health, physical anthropology, sport and exercise sciences, and, more specifically, of kinanthropometry, physiology, biomechanics, auxology and ergonomics. There have been two different, though overlapping, approaches to human body composition analysis: chemical and anatomical. The chemical approach yields the amounts of water, fat, protein and various mineral elements in the different tissues and in the body as a whole. The anatomical approach partitions the body into those components which are readily separable by dissection. These include skin, muscle, adipose tissue, bone and organs.

In combination, the two approaches yield data on the chemical composition of the dissectable tissues (Widdowson et al. 1951, Clarys et al. 1984, Martin and Drinkwater 1991).

It is also general knowledge that monitoring adiposity is a dominant ingredient of body composition analyses and that skinfold measurements (and quantities derived from them) play a key role in the prediction of adiposity. In addition skinfolds have specific applications in occupational biomechanics, human hydrodynamics, drug quantification, diabetes, coronary heart disease, nutrition, endocrinology, hypertension, anorexia nervosa and in many epidemiological and human growth studies. Consequently the skinfold is also a central factor in adipose tissue patterning (Edwards 1951, Garn 1955, 1971, Mueller and Stallones 1981, Mueller 1985), in ‘fat’ distribution studies, in somatotyping (Heath and Carter 1967, and others) and in commercialized systems for monitoring adiposity and proportional mass.

This interest in skinfolds, given the easy accessibility of the subcutaneous layer and its non-invasive nature, has led to a proliferation of skinfold applications and formulae. In the literature, over 1000 articles can be found dealing directly or indirectly with skinfold measurement, both in applied and fundamental research. Altogether more than 100 equations to predict body fat from skinfolds have been produced (Lohman 1981, Martin et al. 1985, Clarys et al. 1987, 1999).

The most common methods for estimating total body fat are densitometry, whole-body potassium counting, body water measurement, anthropometry and, more recently, dual energy X-ray absorptiometry (DEXA), computerized tomography (CT) and magnetic resonance imaging (MRI). In particular, DEXA is gaining support as a criterion method, despite the concerns expressed about its use as such (Wang et al. 1998, Van der Ploeg et al. 2002). Of these, anthropometry is the only technique that is both readily available and inexpensive. Estimation by anthropometry, however, not only too frequently relies for its ‘validation’ on one or more of the other techniques, but also relies on the validity of a number of significant assumptions about body composition.

Over the past two decades it has become clear that fat distribution is a better predictor of morbidity than total fatness. In particular, abdominal obesity is associated with what
has come to be known as the metabolic syndrome, a cluster of adverse changes in glucose
relationship has not been established between fat distribution and these metabolic disturb-
ances, both prospective and epidemiological studies have demonstrated that measures of
visceral fat stores are strong predictors of coronary heart disease and stroke (Larsson 1988) and interest in abdominal, especially visceral, adipose tissue is high. A recent
computer-based literature search indicated that the term ‘fat distribution’ appeared in the
abstracts of more than 1000 journal articles over the last 10 years. Despite this interest,
there is no inexpensive, accurate measure of visceral fatness.

On the other hand, the waist-to-hip girth ratio (WHR) has emerged as a robust index
of health risk. Prospective studies have established that the WHR is predictive of glucose
intolerance, diabetes, cardiovascular morbidity and mortality (Lapidus et al. 1984, Larsson et al. 1984, Ohlson et al. 1985) and even endometrial and ovarian carcinoma
(Lapidus et al. 1988). It is generally assumed that the predictive value of the WHR for
cardiovascular disease and metabolic aberrations stems from its reflection of the body’s
distribution of adipose tissue, which in turn influences health risk. Yet little is known of
what the WHR actually measures; both waist and hip girths encompass a variety of
tissues. It has even been suggested that in non-obese individuals the WHR primarily
assesses muscular and skeletal factors (Smith 1988).

2. Purpose

The aim of this review, therefore, via the analysis of the pooled CAS data (Clarys et al.
1999), was to examine the validity of predicting ether-extractable body fat from skinfold
calliper readings, and to consider instead the prediction of whole-body adiposity and its
adequacy. It was of interest also to report the influence of subcutaneous adiposity and
musculo-skeletal factors on the ability of the WHR to account for the relative
distribution of adipose tissue in the human body.

The data are from three separate whole-body dissection projects (Clarys et al. 1984, Martin
et al. 1984, Clarys and Marfell-Jones 1986, Janssens et al. 1994). These studies (n = 34),
collectively known as the Brussels Cadaver Analysis Study (CAS) were a joint venture between
Simon Fraser University, Burnaby Canada, Göteborg University, Sweden and the Vrije
Universiteit Brussel, Belgium. In addition, further nineteenth-century reports on 12 cadavers
have been located, as have data on five cadavers from the USA, giving a total of 51 adults for
whom body weight and the major tissue weights are known (Clarys et al. 1999).

The results and applications of these various studies are presented in three parts: part I
deals with the basic data and major objectives of the three CAS projects. We highlight the
problematic relationships between gender, internal and subcutaneous adipose tissue
distribution. Part II is focused on the critical appraisal of the skinfold measurement and
the assumptions or hazards that are associated with it. Part III represents an attempt to
improve our comprehension about the body mass index (BMI) and the WHR, and their
relation to various ratios of adipose mass, including total, internal and subcutaneous
values, separately.

2.1. Part I: the Brussels Cadavers Analysis Studies

In the original Brussels Cadaver Analysis study, 13 female and 12 male cadavers, age
range 55–94 years, 12 embalmed and 13 unembalmed, were selected from about 75
cadavers on the basis of least emaciation and most normal appearance (Clarys et al. 1984). After comprehensive anthropometry, each cadaver was dissected into skin, adipose tissue, muscle, bones, organs and viscera. Tissues were separated by six body segments: these were arms, legs, head and trunk. The weight of any fluid separating from the tissue was added back to the tissue weight. All tissues were stored in airtight humidified containers until weighing. The evaporative weight loss occurring through the dissection process, taken to be the difference between pre-dissection body weight and the sum of all tissues after the dissection, was added back to each component in proportion to its weight. This evaporative weight loss was considerable and varied between 2 and 3 l; it was linearly related to the length of time the cadavers were exposed for at room temperature. These quantities may not be surprising, considering the important but variable amounts of water in the separate human body tissues (figure 1). Volumes and densities of all tissues were determined by weighing the tissues underwater. A complete dissection lasted from 10 to 15 h and required a team of about 12 people.

The second study was undertaken to measure the composition of body limb segments and to derive prediction equations for segment weights of skin, adipose tissue, and muscle and bone (Clarys and Marfell-Jones 1986). For these purposes, incomplete dissections were sufficient. However, for three subjects (two 16-year-old males and an 80-year-old female), full dissections were completed with a similar protocol to that of the initial study.

The relationship between body composition estimated by computed tomography and values obtained by dissection and weighing of tissues of three male and three female cadavers, age range 72–88 years, was investigated in a third study (Janssens et al. 1994). The cadavers were dissected into the same components as previously.

For all of the subjects, body height was estimated from the supine length measurement according to a previously derived equation (Martin et al. 1984). Pooling all Brussels data yielded a data set of 34 cadavers, including 17 male and 17 female, with an age range of 16–94 years. Figure 2 shows human tissue weights as a percentage of body weight.

An immediate question that can be raised concerns the validity of applying the relationship found in such a sample to the living. If there are changes in circumferences and segment composition, these changes should be detectable using anthropometry. The relationships should not change to any marked extent, only the absolute values. It is a

![Figure 1. Fluid content (%) of human tissue.](image-url)
major assumption of this study, therefore, that the relationship between anthropometric variables and segment composition in cadavers is similar to their relationship in the living.

We therefore measured *in vivo* 18 elderly male and 22 elderly female subjects ranging in age from 55–92 years (age-match selection). Using a selection of anthropometric measurements also employed in the cadaver sample and determining the somatotype of both the cadaver group and the ‘living’ subjects according to the techniques of Heath and Carter (1967), an overall comparison of the physique of post-mortem and living subjects of a similar age group was made. Apart from a few single measurements it appears that the overall morphology (constitution) of the living and the dead are similar (figure 3). In other words, the use of cadavers does not affect the predictive ability and validity of the models and conclusions generated from it.

The methodology varied for specific items across the different studies depending on the objectives, but these differences appeared to have no effect on the measured weights of the gross tissues. In order to review all adult dissection data the combined nineteenth-century and mid-twentieth century data were added (Bischoff 1863, von Liebig 1874, Theile 1884, Welker and Brandt 1903, Mitchell *et al.* 1945, Forbes *et al.* 1953, 1956, Moore *et al.* 1968). These extra data consisted of 12 subjects in the age range 26–50 years (although there were four subjects of unknown age). Adding the remaining five dissections (1945–1968) yielded a total of 31 men and 20 women for whom the weights of skin, adipose tissue, muscle and bone were known (figures 4 and 5).

Depending of the available data, various adiposity relations are of interest and, although the number of subjects can differ per topic, the most obvious relations or questions were chosen: (i) what relationship, if any, exists between visceral (internal) and whole-body adipose tissue masses (figure 6)? (ii) Can subcutaneous (external) measures...
adequately account for visceral (internal) adiposity (figure 7)? (iii) Can subcutaneous adipose tissue be representative for whole-body adipose tissue (figure 8)?

The answer to these questions is undoubtedly ‘yes’; the relations are good to very good and consequently both the internal and external adipose tissue mass compartments are representative, discriminating and good predictors for the total adipose tissue mass. There is no (inexpensive) accurate measure of visceral fatness, but these data confirm at least (and at last) that whole-body adiposity can be approached via the measurement of subcutaneous adiposity, e.g. with skinfolds introduced into formulae (see part II) or used as a summation.

Evidently, this situation creates new questions, such as whether a sum of skinfolds (e.g. eight) discriminates for both subcutaneous and total body adipose tissue mass. Contrary to what could be expected, this relationship is less straightforward than the relationship

---

**Figure 3.** Normalized anthropometric comparison of age-matched *in vivo* subjects (zero axis) with male and female cadavers.

<table>
<thead>
<tr>
<th>SKINFOLDS</th>
<th>SUBSCAPULAR</th>
<th>TRICEPS</th>
<th>BICEPS</th>
<th>SUPRA ILIACAL</th>
<th>CALF</th>
<th>ARM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIRCUMFERENCES</td>
<td>ELBOW</td>
<td>FOREARM</td>
<td>Wrist</td>
<td>THIGH</td>
<td>SUPRAPATELLAR</td>
<td>CALF</td>
</tr>
<tr>
<td>BREADTHS</td>
<td>Humerus</td>
<td>STYLION</td>
<td>FEMUR</td>
<td>MALLEOLUS</td>
<td>ACROMIAL</td>
<td>THORAX (Frontal)</td>
</tr>
<tr>
<td>LENGTHS</td>
<td>SUPINE</td>
<td>SUSPENDED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEIGHT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A Normalised comparison (Mollison Diagram) of age matched in vivo subjects (zero axis) and Male/Female cadavers.
between internal and external masses (Martin et al. 2003). Not only is the predictive value of the relationship lower, indicating that verification of the measurement procedure is needed, but it also indicates gender influences (figures 9 and 10; see part II).

Clearly, predicting both subcutaneous and whole-body adiposity in females becomes a doubtful procedure. Previously, and in a first approach to this problem, an opposite gender influence had been suggested (Clarys et al. 1987).

2.2. Part II: critical appraisal of a skinfold measure

The skinfold-calliper measure has become a routine laboratory and field method that has obtained a status of ‘tradition’. In other words, this measure has become too normal, almost too obvious to analyse it.

Hägar (1981) stated that ‘two important assumptions must be made in the calculation of body skinfold measurements: (1) subcutaneous fat constitutes a constant proportion of total body fat over all ranges of body weight, and (2) the sites of measurement are representative of all subcutaneous fat.’ This statement is, at best, doubtful.
What is really being measured is the thickness of a double skinfold and compressed subcutaneous adipose tissue. To infer the mass of fat in the body from this measure requires another series of assumptions whose validity has never been seriously challenged (Clarys et al. 1987). In order to review the (old and new) assumptions associated with the calliper adiposity transformations, our previous ‘step by step’ model (Martin et al. 1985, Clarys et al. 1987) and its renewed version (Marfell-Jones and Drinkwater 2003) are relevant. The transformation from calliper reading to total body adiposity can be divided into a number of steps. The thickness of a compressed double layer of skin and subcutaneous adipose tissue should be representative of the uncompressed single layer of adipose tissue. This should indicate total subcutaneous adiposity, from which internal and whole-body adiposity can be predicted. Based on the pooled cadaver data, we have (again) reviewed facts, assumptions and hazards to be taken into account in the transformation of skinfolds to whole-body adipose tissue mass.

Figure 11 presents a flow-chart of the systematic follow-up of the calliper reading with its associated five assumptions. Each of these is considered separately in chronological order.

2.2.1. A calliper produces a constant skinfold compressibility (assumption I). Most workers adopt some strategy to standardize the calliper reading in spite of its dynamic characteristics. Some wait ‘for all needle movements to cease’ before taking the reading while others record after ‘an initial rapid phase of the movement’ or read after 2 or 4 s of applied pressure.
In addition to the dynamic compressibility, there is also a static element. Even after standardizing the timing of the calliper reading, similar thicknesses of adipose tissue may yield different calliper values due to different degrees of tissue compressibility. Since the Brussels CAS data include both skinfold thickness and the direct depth measurement (after incision) of the thickness of the subcutaneous adipose tissue layer, skinfold compressibility could be obtained for each site (Marfell-Jones and Drinkwater 2003). It was found that skinfold compressibility is by no means constant.

2.2.2. Skin thickness is a negligible part or a constant fraction of the skinfold (assumption II). All skinfold measurements contain a double layer of skin of unknown thickness. If this is very small in comparison to the skinfold measurement, its influence may be negligible. Data on skin thickness are sparse. A comprehensive review of skin thickness and surface data is to be found in Clarys et al. (1988). The site where the effect of skin thickness was most marked was the subscapular, where skin thickness accounted for 28.1% of the skinfold reading (34.0% for males, 23.9% for females). The subscapular and triceps sites are most commonly used for predicting whole-body values but have quite different proportions of skin (Clarys et al. 1987). Consequently, on the basis of skin thickness, the subscapular skinfold should be a poorer predictor than skinfolds at arm and leg sites.

Figure 7. External (subcutaneous) versus total body adipose tissue.
2.2.3. Adipose tissue patterning is fixed (equal) all over the body (assumption III). ‘Fat patterning’ refers to differences in the anatomical placement of adipose tissue (Mueller 1985) and should therefore more accurately be referred to as ‘adipose tissue patterning’. The patterning of subcutaneous adipose tissue is known to exhibit very large variations between individuals (Mueller and Stallones 1981, Clarys et al. 1988).

To assess the value of various sites as predictors of subcutaneous adiposity, correlations between the calliper and incision thickness with the dissected subcutaneous adipose tissue mass have been determined (Clarys et al. 1987). An unexpected finding is the high correlation for lower limb sites. Of the six best sites, all but one were on the lower limb. The triceps, a highly favoured site for ‘fat’ prediction and considered to be the single indicator of adipose tissue (e.g. in digitized commercial devices) ranked a poor eleventh. The best predictors were front thigh, medial calf, rear thigh and supra-spinale.

In summary, adipose tissue patterning is under no circumstances equally divided over the body.

2.2.4. Predicting fat of the human body is conditional to the knowledge of the fat content of or in adipose tissue (assumption IV). Even if the mass of subcutaneous adipose tissue was known exactly, the prediction of subcutaneous fat mass requires some assumptions concerning the fat content of adipose tissue. Reported values range from 5.2 to 94.1%
Figure 9. Sum of skinfolds (8) vs. external (subcutaneous) adipose tissue.

Figure 10. Sum of skinfolds (8) vs. total body adiposity.
Martin 1984), but they are generally in the range 60–85%. Further, the fat content of adipose tissue increases with increasing adiposity.

In view of considerations such as these, compounded by the fact that ‘fat’ is ether-extractable, whereas ‘adipose tissue’ is an anatomical–morphological entity, confusion of the two (as is too often the case) should be avoided by eliminating ‘fat’ terminology from all morphologically based predictions of adiposity (Clarys et al. 1987).

2.2.5. A high correlation between internal, external and adiposed tissue obtained from skinfolds is essential (assumption V). From evidence based on cadaver studies it is assumed that, both in male and female subjects, the excess of adipose tissue is piled up subcutaneously, intramuscularly and internally, mostly in the trunk. The amount of intramuscular fat in the obese should not be underestimated and should therefore be considered as a third compartment. However, in our cadaver analysis and for this purpose, the intramuscular amount was allocated to the internal adipose tissue. Skinfold
callipers are only able to estimate subcutaneous adiposity. In order to estimate total body adiposity, some assumptions must be made about the relationship between internal and subcutaneous adipose tissue. If internal adiposity stores are proportional to subcutaneous adiposity, this relationship provides a rationale for use of skinfold callipers. An alternative is that internal adipose tissue may be negligible compared with subcutaneous adipose tissue, again providing some justification for the use of callipers.

If, however, there is no significant relation between internal and subcutaneous adipose tissue masses, and/or internal adiposity stores are far from negligible, then there cannot be any evidence-based prediction of total body adiposity, and concomitantly, there is no justification for using calliper measurements if these do not correlate with the above.

Part I provided comprehensive data on the relation of external (or subcutaneous) adipose tissue to internal (or visceral) masses (figures 6–8). These data indicate a good correlation between external and internal mass in both men \((r = 0.72)\) and women \((r = 0.86)\); on the other hand, the relationship in females between the sum of skinfold and total adipose tissue is very poor.

Almost all assumptions necessary to convert skinfold calliper readings to percentage ether-extractable fat are clearly unfounded, which means that we can have no confidence in the correctness of any whole-body fat prediction that depends on these assumptions. For this reason, we recommend again a complete rejection of the use of the term ‘fat’, in favour of the term ‘adipose tissue’, which is in fact what is being measured by skinfold callipers.

Having rejected the concept of the prediction of body fat, we next considered whether, instead, total body adiposity could be confidently predicted from skinfolds. To achieve this, skinfold measures would need to predict subcutaneous adipose tissue mass adequately, and there would need to be a strong relationship between the latter and total body adiposity.

The most commonly used sites for skinfold measurements (in a variety of combinations) are triceps, subcapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf. The use of all of these sites gives an achievable, reasonably comprehensive coverage of the body’s subcutaneous adipose tissue deposition. For this reason the relationship between the sum of these eight skinfolds and the subcutaneous adipose tissue masses of all those CAS subjects for whom these data were available \((n = 20)\) was examined. Figure 9 shows a strong significant correlation between these entities in men \((r = 0.82)\), but a poor relationship in women \((r = 0.56)\). The reason for the gender difference is unclear at this point and is the subject of ongoing investigation. This important difference in basic relations (skinfolds vs. adipose tissue) also jeopardizes the use of skinfold measures. ‘Skinfold for men only’ seems somewhat obtuse.

In terms of a conclusion of part II, the CAS data clearly indicate that many assumptions in the step-by-step transformation from skinfold measurement to whole-body fat are invalid or highly variable. Therefore, it is unreasonable to continue to introduce known error into the prediction or determination of total body fat by combining and transforming anthropometric (skinfold) values, especially, within formulae. On the positive side, however, a strong relationship between external (subcutaneous) adiposity and total body adiposity was confirmed. Unfortunately the summation of the best predictive skinfolds allows the estimation of total adipose tissue only in men.

### 2.3. Part III: whole-body adiposity, BMI and WHR

The distribution of the body’s adipose tissue mass is an important indicator of health risk. Central (visceral or internal) adipose predominance is a strong risk factor for

Assuming that the musculo-skeletal structure is the main factor regulating WHR, the relationship between WHR and adipose tissue distribution should be improved by replacing WHR with an analogous ratio derived from the waist and hip girths with subcutaneous adipose tissue removed. To test this supposition, WHR was measured in adult cadavers before and after removal of all skin and subcutaneous adipose tissue.

On the other hand, we do realize the popularity of the BMI, serving a similar purpose. In reality it is a poor predictor of health risk, in particular in its relation to body adiposity (figure 12).

Waist girth made significant contributions to the variation in trunk adipose mass ($p < 0.001$) and internal adipose mass ($p < 0.05$; table 1); the amount of variation explained by waist girth was 37.2% for trunk adipose mass and 7.7% for internal adipose mass. With the skin and subcutaneous adipose tissue removed, waist girth (minus adipose tissue = waist $gx$) displayed a significant relationship with trunk adipose mass ($p < 0.02$), accounting for 16.4% of the variation in trunk adipose mass, but waist $gx$ was not related to internal adipose mass.

Hip girth accounted for highly significant ($p < 0.0001$) portions of the variance in adipose mass of arm-plus-leg and leg adipose mass, explaining 63.1 and 59.2% of the variation in each dependent variable, respectively. Hip girth (minus adipose tissue = hip $gx$) was not significantly related to arm-plus-leg adipose mass nor to leg adipose mass (Martin et al. 2003).

The data demonstrate consistently significant relationships of WHR but not WHRx (waist-to-hip girth ratio minus adipose tissue) with mass ratio indicators of adipose tissue distribution in male and female cadavers. These results directly validate the WHR as an indicator of central relative to peripheral adipose tissue distribution in humans and also

![Figure 12. The relationship between BMI (kg/m$^2$) and total body adiposity (%).](#)
Table 1. Relationship of waist and hip girths, and waist and hip girths with skin and subcutaneous adipose tissue removed (waist gx and hip gx), to regional adipose masses in 22 cadavers, by analysis of variance (x indicates removal of adipose tissue in the waist-to-hip girth ratio).

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Factors</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk adipose mass</td>
<td>Waist girth</td>
<td>0.0007</td>
</tr>
<tr>
<td></td>
<td>Waist gx</td>
<td>0.015</td>
</tr>
<tr>
<td>Internal adipose mass</td>
<td>Waist girth</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>Waist gx</td>
<td>0.419</td>
</tr>
<tr>
<td>Arm-plus-leg adipose mass</td>
<td>Hip girth</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>Hip gx</td>
<td>0.055</td>
</tr>
<tr>
<td>Leg adipose mass</td>
<td>Hip girth</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>Hip gx</td>
<td>0.089</td>
</tr>
</tbody>
</table>

indicate that the predictive value of the WHR in this respect stems from the subcutaneous adipose tissue at the waist and hip and not the underlying musculo-skeletal structure (Marfell-Jones and Drinkwater 2003, Martin et al. 2003).

In summary, we have provided direct evidence which validates the WHR as an indicator of central relative to peripheral adipose tissue distribution in humans, as well as evidence validating waist girth as an indicator of central adiposity and hip girth as an indicator of peripheral adiposity. In addition our observations indicate that the musculo-skeletal structures of waist and hip are not related by girth measurement to the regional distribution of adipose tissue in the body unless they include the overlying skin and subcutaneous adipose tissue. In our sample, the ability of the WHR and the waist and hip girths to reflect regional adiposity was entirely dependent upon the subcutaneous adipose tissue of the waist and pelvis.

References


