Surface Anthropometric Indices in Obesity-related Metabolic Diseases and Cancers

Chao-Yang Yang, PhD; Chien-Yu Peng, MS; Ying-Chieh Liu, PhD; Wen-Zhi Chen, PhD; Wen-Ko Chiou, PhD

Metabolic syndrome (MetS), cardiovascular diseases (CVD) and cancers such as colon cancer (CCa), prostate cancer (PCa) and breast cancer (BCa) have been recognized as obesity-initiated diseases. The development of obesity can cause changes in metabolic and hormonal conditions, which can result in the storage of excess energy in different forms in the human body. Existing anthropometric data are useful in the prognosis of these diseases. Although frequently studied, there is disagreement on the applicability, reliability and trends of weight, height, waist circumference (WC) and relevant indices. WC is generally accepted as a key marker in CVD and CCa risk assessment whereas more evidence of the usefulness of WC-CVD, WC-PCa and WC-BCa correlations is needed. The body mass index, which has been widely used as a determinant of obesity, has a strong connection with CCa risk in men and young women, but an inconsistent connection with BCa. Cross-referencing measurements, with indices such as the waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR), enhances the association with diseases, e.g. WHtR-CVD and WHR-CCa, and connections are strong. This idea is further applied to multiple referencing. For example, the WHtR/WHR has been studied and found highly correlated with the MetS risk in Asia. In addition, latent issues (such as tools or techniques for surface anthropometric measurement), which could affect the prognosis of diseases, have been discussed. To this end, three-dimensional technology is suggested as a reliable tool for various anthropometric data collection and analysis in preventive medicine. (Chang Gung Med J 2011;34:1-22)

Key words: obesity, anthropometric indices, metabolic syndrome, cardiovascular diseases, cancer, measurement error

Obesity has been associated with negative health impacts, including metabolic syndrome (MetS), cardiovascular diseases (CVD) and some types of cancers.1-7 During the development of these obesity-related diseases, metabolic and hormonal conditions are changed when excess energy is stored in different forms such as body fat (BF) and cholesterol. The major causative factor is thought to be hormones...
which mediate metabolic control (insulin and leptin), cell growth (insulin-like growth factor I, IGF-I, and IGF-binding proteins) and reproduction (steroids and leptin).\(^{59}\) Moreover, a diagnosis of MetS requires at least of 3 of 5 risk factors of CVD and diabetes including abdominal obesity, elevated fasting blood glucose, elevated blood pressure, hypertriglyceridemia, and low levels of high density lipoprotein.\(^{9}\) Abdominal and visceral fat in particular have been implicated as major risk factors for MetS.\(^{10,11}\)

Of the top 5 causes of cancer mortality in the United States, which are lung, colon, breast, prostate, and pancreas cancer, adiposity likely plays an important role in all but lung cancer.\(^{12}\) Individuals with MetS have been found to have an elevated risk of developing colon cancer (CCa),\(^{13-16}\) Breast cancer (BCa) and prostate cancer (PCa) are the most common cancers worldwide among women and men, respectively.\(^{17,19}\) Several meta-analyses have shown that body mass index (BMI) is associated with cancer risk in the colon, breast, and prostate.\(^{19-24}\) However, the biological mechanisms linking obesity with increased cancer risk and mortality are not entirely consistent and many hypotheses have been generated to explain this association. For example, numerous epidemiological studies have shown that high serum levels of IGF-I correlate with increased cancer risks in PCa,\(^{25-27}\) CCa\(^{28-30}\) and premenopausal BCa.\(^{31,32}\) There are significant associations of BMI with IGF-I levels and of all anthropometric variables, except body height (BH), with negative health outcomes.\(^{33}\) Therefore, in this review, the development of CCa, PCa and BCa will be discussed in relation to surface anthropometric indices.

Recent research has suggested that the distribution of BF may affect the development of diseases. For example, adipose tissue in the thigh is protective against MetS,\(^{34}\) and a high ratio of abdominal to thigh fat is most predictive of CVD.\(^{35,36}\) However, the distribution of BF is difficult to measure directly through existing techniques. While BMI is the most commonly used fat-related risk index,\(^{37}\) anthropometric indices of abdominal fat, such as waist circumference (WC) and waist-to-hip ratio (WHR), are better at explaining MetS, CVD and cancers relevant to adiposity.\(^{38-40}\)

Body dimensions are related to growth, age and fitness in healthy subjects and have been used for centuries as indices for acute and long-term diseases in clinical medicine.\(^{41}\) However, the need for accurate body measurements has increased as knowledge about their relationship with health risks is accumulating. Recently, three dimensional (3D) body scanning, which provides a detailed body shape, has been proposed as a sophisticated tool for accurately measuring obesity status, and allowing for the identification of those most at risk of MetS,\(^{42-46}\) hypertension,\(^{47}\) Type 2 diabetes\(^{48,49}\) and CVD.\(^{41,50}\) Body surface dimensions should not therefore be regarded as a primitive approach for describing BF distribution. 3D body scanning has a potential major role to play in both epidemiological studies of the risk of MetS and the monitoring of individual patients in response to treatment.\(^{51}\) Although measuring body shape, including volumes and dimensions, can provide important information to investigators for research or clinical purposes, no single widely accepted technique can simultaneously measure the multiple variables that determine body shape.

Because of instrument imprecision and human inconsistencies, measurements are not free of error. In the measuring process, doctors play an important role in examinations of obesity and associated health risks.\(^{52}\) Anthropometric studies have shown excellent reproducibility for body weight (BW), BH and derived BMI, but unsatisfactory reproducibility for WC and the WHR\(^{53}\) in intra-observer and inter-measurer reproducibility of these measurements.\(^{53-57}\) Serious measurement inaccuracy can influence results of health examinations and influence the diagnosis, and in this setting may result in health problems remaining undetected. If commissioners of health services are to be informed by these data, then it is important to address their reliability. External observation is recommended to improve validity.\(^{57}\)

By triangulating various anthropometry measurements, the chance of finding biologically true differences is increased.\(^{58}\)

The main purpose of this review is to investigate the applicability of existing measurement techniques in assessing the risk of MetS, CVD, CCa, PCa and BCa. As with previous research,\(^{5,8-9,63}\) this review commenced by looking at keywords such as obesity, CCa, PCa, BCa, CVD, MetS, BMI, WC and WHR, obesity-related diseases and surface anthropometrics. First, the background and present conditions of the diseases are introduced. Next, surface anthropometric indices with relationship to MetS, CVD, CCa,
PCa and BCa are compared. Finally, latent issues and limitations, such as measurement errors of surface anthropometric indices, are reviewed; finally, the appropriateness of different techniques is addressed.

**Surface anthropometric indices and MetS**

The BMI is significantly correlated with adiposity\(^{64,65}\) and can predict the BF percentage adequately when age and gender are considered\(^{66,67}\). However, the BMI is not a useful predictor of variables associated with MetS as it does not provide information on how BF is deployed\(^{66}\). There is no doubt that abdominal anthropometric indices contribute important information about abdominal obesity in relation to MetS. Several organizations advocate WC measurement as a component of the criteria for MetS\(^{68-72}\).

**Table 1. Surface Anthropometric Indices and MetS in Different Regions**

<table>
<thead>
<tr>
<th>Regions</th>
<th>Fat-related anthropometry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asia</td>
<td>Others</td>
</tr>
<tr>
<td>Lin et al., 2002(^{44})</td>
<td>Taiwan</td>
<td>†</td>
</tr>
<tr>
<td>Hsieh et al., 2003(^{84})</td>
<td>Japan</td>
<td>†</td>
</tr>
<tr>
<td>Syed et al., 2009(^{85})</td>
<td>Pakistan</td>
<td>*</td>
</tr>
<tr>
<td>Lee et al., 2008(^{88})</td>
<td>Korea</td>
<td>†</td>
</tr>
<tr>
<td>Kato et al., 2008(^{87})</td>
<td>Japan</td>
<td>*</td>
</tr>
<tr>
<td>Lear et al., 2002(^{76})</td>
<td>China</td>
<td>Europe</td>
</tr>
<tr>
<td>Perry et al., 2008(^{89})</td>
<td>Americans</td>
<td>*</td>
</tr>
<tr>
<td>Shen et al., 2006(^{50})</td>
<td>Americans</td>
<td>†</td>
</tr>
<tr>
<td>Bosy-Westphal et al., 2006(^{79})</td>
<td>Poland</td>
<td>†</td>
</tr>
<tr>
<td>Wannamethee et al., 2005(^{49})</td>
<td>British</td>
<td>†</td>
</tr>
</tbody>
</table>

**Abbreviations:** BMI: body mass index; WHR: waist-to-hip ratio; WHtR: waist-to-height ratio; WC: waist circumference; *: 0.01 < p ≤ 0.1, moderate correlation; †: p ≤ 0.01, strong correlation.
However, significant clinical evidence has indicated that individual differences can affect MetS risk judgments. For example, overweight Asian individuals do not reach the cut-off point used in Western countries but still have a substantially higher risk of MetS than their leaner Asian counterparts and heavier Western counterparts.(73-75)

Recent research suggests that WC is a better index for assessing BF distribution(76) and prefer it to the WHR because of simplicity of measurement, ease of interpretation(77) and also the stronger relationship with MetS in the United States and Europe.(68,76,78-80) However, limitations of these indices have been emphasized by other investigators from a statistical point of view.(81,82) For example, short people may still face higher metabolic risks than tall people with similar WC;(80) obese and lean individuals can have equal values for the WHR; an increased WHR may indicate either increased visceral fat or reduced muscle mass as quantified by HC.(83)

Accordingly, recent studies found that cross-referencing of the WHtR and WHR index results is a better index for assessing BF distribution and results in a stronger correlation with MetS in Asian.(44,73,74,84-86) However, a composite index generally has more measurement inaccuracy than either the WHtR or WHR alone.(87) This inaccuracy is generally considered to be a research limitation of sampling bias, (44,86) differential measuring definitions and human measurement errors.

Surface anthropometric indices and CVD

Studies have found that total fat as well as abdominal fat distribution play an approximately equal role in CVD.(88) Recently, a great quantity of data has confirmed the importance of central adiposity as a CVD risk factor, with WC explaining a greater variance of the CVD risk factors than the BMI.(91)

Despite the strong association between central adiposity and CVD risks, employing anthropometric indices for CVD risk results in varied findings: (1) WC has a stronger correlation than the WHR with visceral fat(92) and CVD(93) (2) WC has been widely demonstrated to be a predictor of CVD risk factors in both genders(94-96) but, some studies have found a low correlation.(97) (3) In the Nurses’ Health Study, both the WHR and WC accurately predicted coronary risk, especially in women.(98) (4) Researchers(98,99) have identified that the WHR is comparable to or more strongly associated with CVD than WC and the BMI whereas others(100,101) believe this is only true in women.

Among four anthropometric indices (BMI, WC, WHR and WHtR), the WHtR is the best discriminator of CVD risk factor for both genders in Asia,(102,104) in Western countries,(106,107) and in Iran.(102) Further, the WHR shows better CVD prediction than multiple uses of indices, e.g. cross referencing of the BMI and WC.(108) To sum up, waist-related indices are more precise than the BMI in predicting CVD in women whereas the WHtR is a more appropriate measure than the BMI and WC in men.

Surface anthropometric indices and CCa

The positive correlation between the BMI and the risk of CCa has been well studied and is generally accepted.(28) However, some studies have identified that gender differences could affect the diagnosis of CCa. For example, men with CCa show stronger correlation with a high BMI.(109-115) Some studies have found no association between the BMI and CCa in women.(110-118) One potential reason for the discrepancy is that men and women have different body shapes, i.e. the BW to BF distribution differs between genders. For example, heavier males tend to have larger abdomens whereas heavier females tend to have more gluteofemoral BF.(119) Age difference significantly affects the BMI-CCa association in women but not men, with the BMI tending to have a stronger association with CCa in young women.(120)

In summary, available epidemiologic evidence suggests that abdominal obesity is more predictive of CCa risk than overall obesity for all ages, but with gender differences. On the contrary, WC and the WHR generally show better consistency in relation to CCa risk than the BMI, especially in women.(118,122,123)

Surface anthropometric indices and PCa

BW and its relationship with PCa is disputed. Some studies showed that overweight men have an increased risk of aggressive PCa,(127-130) while other
studies concluded no association exists. The correlation between the risk of total PCa incidence and BMI has been further repudiated, as well as that for BH and body mass. Additionally, there is little evidence for an association with central obesity. Some studies found a direct relationship between PCa risk and the WHR, whereas reports from the United States and Europe found no association.

Apart from this inconsistency, indices have been found to be associated with PCa. Chan et al. reported a strong positive association between levels

Table 2. Surface Anthropometric Indices and Cardiovascular Disease (CVD) by Gender

<table>
<thead>
<tr>
<th>Fat-related anthropometry</th>
<th>BMI</th>
<th>WC</th>
<th>WHR</th>
<th>WHtR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perry et al., 1998</td>
<td>†_F</td>
<td></td>
<td></td>
<td></td>
<td>Higher BMI was not solely responsible for increases in CVD risk factors.</td>
</tr>
<tr>
<td>Bertsias et al., 2003</td>
<td>†_F</td>
<td>†_M</td>
<td></td>
<td></td>
<td>WC in women and WHtR in men were strong indicators for abnormal serum lipids and lipoproteins.</td>
</tr>
<tr>
<td>Ho et al., 2001</td>
<td>*_M</td>
<td>*</td>
<td>*_F</td>
<td></td>
<td>There were significant gender differences in the association between central or general obesity with CVD risk factors (WC_M, BMI, WC_F, WHR).</td>
</tr>
<tr>
<td>Mellati et al., 2009</td>
<td>*</td>
<td>†</td>
<td>*</td>
<td>†</td>
<td>Area under curve of WHtR was the largest for most of the common CVD risk factors in both men and women.</td>
</tr>
<tr>
<td>Shahraki et al., 2008</td>
<td>†_F</td>
<td>†_F</td>
<td></td>
<td></td>
<td>WC was better for predicting some CVD risk factors in young and middle-aged women; however, for older women, WHR was better.</td>
</tr>
<tr>
<td>Turcato et al., 2000</td>
<td>†</td>
<td>*_F</td>
<td>†_F</td>
<td></td>
<td>WC was the anthropometric indicator of fat distribution most closely related to CVD risk factors in old age.</td>
</tr>
<tr>
<td>Maffeis et al., 2001</td>
<td>†</td>
<td></td>
<td></td>
<td></td>
<td>Multivariate logistic regression analysis revealed that children with a WC above the 90th percentile for sex and age have a higher probability of having CVD risk factors.</td>
</tr>
<tr>
<td>Sharp et al., 2003</td>
<td>*</td>
<td>†</td>
<td></td>
<td></td>
<td>Using more than one anthropometric measure in multiple regression did not improve predictions of risk over using a single predictor.</td>
</tr>
<tr>
<td>Rezende et al., 2006</td>
<td>*</td>
<td>†</td>
<td></td>
<td></td>
<td>Most correlations between anthropometric indices and risk factors for CVD were significant, but weak. WC had the strongest correlation and was associated with the largest number of variables.</td>
</tr>
<tr>
<td>Botton et al., 2007</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td>The correlations between CVD risk factors and WC or WHtR were roughly similar.</td>
</tr>
<tr>
<td>Hara et al., 2002</td>
<td>*</td>
<td></td>
<td></td>
<td>†</td>
<td>WHR was the best predictor of CVD risk in children.</td>
</tr>
</tbody>
</table>

Abbreviations: M: male; F: female; BMI: body mass index; WC: waist circumference; WHR: waist-to-hip ratio; WHtR: waist-to-height ratio; *: 0.01 < p ≤ 0.1, moderate correlation; †: p ≤ 0.01, strong correlation.
of plasma IGF-I in adults and PCa risk, and previous studies have also suggested a relationship between IGF-I and PCa,(161,162) suggesting that tall men may be exposed to higher levels of IGF-I and androgens during adolescence. Furthermore, serum prostate-specific antigen (PSA) has been widely used to detect PCa, and prostate volume and body surface area are significant factors for predicting PSA levels.(154)

**Metabolic and hormonal factors** have also been implicated in female BCa prognosis(176,177) and the relationship between body size and BCa risk has been investigated in numerous studies. Initially, studies focused on the association between body size consistency (i.e. BW(62,178-182) or BH (24,178,180,181,183) ) and BCa. Recently, it has been postulated that enlarged body areas, such as the waist or hips, may play a key role in the development of BCa. Both WC and hip circumference (HC) are highly related to the risk, and also highly correlated to each other, so calculat-

### Table 3. Surface Anthropometric Indices and Colon Cancer (CCa) by Gender

<table>
<thead>
<tr>
<th>Description</th>
<th>BMI</th>
<th>WC</th>
<th>WHR</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adams et al., 2007(120)</td>
<td>†_M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacInnis et al., 2004(109) **</td>
<td>_M</td>
<td>†_M</td>
<td>†_M</td>
<td>†_BH_M</td>
</tr>
<tr>
<td>MacInnis et al., 2006(116)</td>
<td>ns_F</td>
<td>*_F</td>
<td>†_F</td>
<td></td>
</tr>
<tr>
<td>Caan et al., 1998(126)</td>
<td>†_M</td>
<td>†_M</td>
<td>†_BW</td>
<td></td>
</tr>
<tr>
<td>Pischon et al., 2006(119)</td>
<td>_M</td>
<td>†_F</td>
<td>†_BW_M</td>
<td></td>
</tr>
</tbody>
</table>

**Abbreviations:**  M: male; F: female; BMI: body mass index; WC: waist circumference; WHR: waist-to-hip ratio; BH: body height; ns: p > 0.1, not significant; *: 0.01 < p ≤ 0.1, moderate correlation; †: p ≤ 0.01, strong correlation.

**Surface anthropometric indices and BCa**

BCa is linked to reproductive and hormone-related factors, such as age at menarche, parity, age at menopause,(163) endogenous sex hormone levels,(164,165) and also exogenous estrogens and progestagens.(166) An increased BCa incidence occurs in parallel with increased frequency of type 2 diabetes and MetS.(167) Thus low levels of high density lipoprotein,(168) high blood glucose,(169) high triglycerides,(170) postmenopausal overweight,(171) abdominal obesity,(172) hypertension,(173) and high levels of insulin,(174) C-peptide(175) and IGF-I(166) are all associated with BCa risk.
Table 4. Surface Anthropometric Indices and Prostate Cancer (PCa)

<table>
<thead>
<tr>
<th>Description</th>
<th>BMI</th>
<th>WC</th>
<th>HC</th>
<th>WHR</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>No variables (BW and BMI) displayed any consistent relation with the risk of PCa.</td>
<td>ns</td>
<td>ns_BW</td>
<td></td>
<td></td>
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<tr>
<td>BMI was only weakly and positively associated with PCa after adjustment for age.</td>
<td>ns</td>
<td></td>
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<tr>
<td>After adjusting for race, age, and birth year, there was no association between BH, BW, BM and PCa risk in the full cohort.</td>
<td>ns_BW, BH</td>
<td></td>
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<tr>
<td>All odds ratios estimated for current BW, BMI, WC, HC and WHR were close to null. No association was found between any measures of anthropometry including several derived measures of changes in weight over lifetime and PCa risk.</td>
<td>ns_BW, ns_BH</td>
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</tr>
<tr>
<td>BH, BW, BMI, WHR, and lean body mass 1 year before diagnosis/interview were not significantly associated with risk.</td>
<td>ns_BW, ns_BH</td>
<td></td>
<td></td>
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<tr>
<td>Serum prostate-specific antigen (PSA) has been widely used to detect PCa. Multivariate analysis revealed that prostate volume and body surface area were significant factors for predicting the PSA level.</td>
<td>*_PSA, *_PV</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>No consistent associations were found for PCa either for BMI or height.</td>
<td>ns_BH</td>
<td></td>
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<tr>
<td>This population-based case-control study revealed that higher levels of WHR and a smaller HC were significant risk factors for clinically overt PCa in China. These results suggested that BF distribution rather than overall obesity plays a role in PCa etiology. A larger HC was associated with a reduced risk of PCa independent of WHR.</td>
<td>ns, *</td>
<td></td>
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</tr>
<tr>
<td>General adiposity, expressed as BMI or BF percentage, was not associated with PCa risk. WHR, a measure of central adiposity, was positively associated with PCa before age 65.</td>
<td>*</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>A greater WHR was associated with an increased, but not statistically significant, risk of PCa in both age-adjusted and multivariate-adjusted analyses. No associations were seen for WC.</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall, the data did not indicate that adiposity correlates with a higher risk of PCa.</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No overall association was found between PCa and any anthropometric measurement (including BF and BMI).</td>
<td>ns_BF</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Abbreviations: M: male; F: female; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-to-hip ratio; BF: body fat; ns: p > 0.1, not significant; *: 0.01 < p ≤ 0.1, moderate correlation; †: p ≤ 0.01, strong correlation.
Table 5. Surface Anthropometric Indices and Pre- and Post-menopausal Breast Cancer (BCa)

<table>
<thead>
<tr>
<th>Fat-related anthropometry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMI</strong></td>
<td></td>
</tr>
<tr>
<td><strong>WC</strong></td>
<td></td>
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<tr>
<td><strong>HC</strong></td>
<td></td>
</tr>
<tr>
<td><strong>WHR</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5. Surface Anthropometric Indices and Pre- and Post-menopausal Breast Cancer (BCa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Folsom et al., 2000</strong> (99)</td>
</tr>
<tr>
<td><strong>Rinaldi et al., 2006</strong> (184)</td>
</tr>
<tr>
<td><strong>Shu et al., 2001</strong> (190)</td>
</tr>
<tr>
<td><strong>Kaaks et al., 1998</strong> (199)</td>
</tr>
<tr>
<td><strong>Sonnenschein et al., 1999</strong> (200)</td>
</tr>
<tr>
<td><strong>Galanis et al., 1998</strong> (230)</td>
</tr>
<tr>
<td><strong>Tung et al., 1999</strong> (231)</td>
</tr>
<tr>
<td><strong>Li et al., 2000</strong> (232)</td>
</tr>
<tr>
<td><strong>Tian et al., 2007</strong> (233)</td>
</tr>
<tr>
<td><strong>Nemesure et al., 2009</strong> (234)</td>
</tr>
<tr>
<td><strong>Friedenreich et al., 2002</strong> (235)</td>
</tr>
<tr>
<td><strong>Shin et al., 2009</strong> (236)</td>
</tr>
<tr>
<td><strong>Montazeri et al., 2008</strong> (237)</td>
</tr>
<tr>
<td><strong>Lahmann et al., 2004</strong> (238)</td>
</tr>
<tr>
<td><strong>Lahmann et al., 2003</strong> (239)</td>
</tr>
<tr>
<td><strong>Verla-Tebit &amp; Chang-Claude, 2005</strong> (240)</td>
</tr>
<tr>
<td><strong>Riza et al., 2009</strong> (241)</td>
</tr>
</tbody>
</table>

**Abbreviations:**  BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-to-hip ratio; BH: body height; BW: body weight; ns: p > 0.1, not significant; *: 0.01 < p ≤ 0.1, moderate correlation; †: p ≤ 0.01, strong correlation; pre: pre-menopausal; post: post-menopausal.
ing the ratio between the two measures could accurately reflect the cancer risk. Additionally, indicators such as BMI, WC, and the WHR have all been highly associated with BCa risk. Women with central adiposity may have a higher risk of BCa than those in which BF is mainly distributed subcutaneously over the hips, buttocks and lower extremities. 

However, this correlation is different in the menopause group according to body indices. For example, increased BW or BMI may confer an increased BCa risk in premenopausal and postmenopausal women. During the premenopausal period, BCa risk is associated with general adiposity (i.e. higher BW and BMI), but has little association with central adiposity (i.e. WC and WHR), whereas postmenopausal women in both general and central adiposity groups face higher BCa risks.

Correlations between the WHR and BCa have been further examined with discrepant associations in both pre- and postmenopausal women. For example, the WHR and BCa are reported by some researchers to be strongly linked in both the postmenopausal and premenopausal period, whereas others reported no significant association in either premenopausal or postmenopausal groups.

Because of the discrepancy in the correlation with these body measurements, researchers are looking for better body indices for the prognosis of BCa. As greater upper or central BF distribution is associated with multiple hormonal and metabolic changes, chest circumference (CC) appears to be a stronger determinant of mammographic patterns than BF distribution (measured as the WHR). It is widely accepted that mammographic parenchyma patterns are a strong independent risk factor for BCa, so CC is possibly an efficient risk indicator.

**Limitations in body surface measurements**

These anthropometric measures have the potential to assist in the assessment of obesity-related MetS, CVD, CCa, and BCa risk and are also easy to perform in clinical practice. However, some limitations, which can influence both risk prognosis and nutritional status interpretation, are little considered. These include human mechanical deviations and deviations between different measuring tools.

Although measurement criteria has improved, inter-measurer issues remain an important cause of deviation. Circumference measurements have shown strong inter-measurer deviations. Differences as large as 3 cm have been obtained in measurements in the same subject. Expertise also affects the outcome, as differences in measurement of more than 1 cm have been found between expert and novices. Differences can be caused by the

<table>
<thead>
<tr>
<th>WC</th>
<th>HC</th>
<th>WHR</th>
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<tr>
<td>Sebo et al., 2008</td>
<td>Inter 0.92</td>
<td>Inter 0.72</td>
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<td>Ulijaszek &amp; Kerr, 1998</td>
<td>Intra 0.97</td>
<td>Inter 0.94</td>
</tr>
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<td>Adams et al., 2002</td>
<td>TEM 0.6</td>
<td>TEM 1.6</td>
</tr>
<tr>
<td>Sonnenschein et al., 1993</td>
<td>Intra 0.89</td>
<td>Intra 0.81</td>
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<tr>
<td>Meunier &amp; Yin, 2000</td>
<td>Intra 0.99</td>
<td>Intra 0.99</td>
</tr>
<tr>
<td>Rimm et al., 1990</td>
<td>Intra 0.88_M, 0.88_F</td>
<td>Intra 0.89_M, 0.88_F</td>
</tr>
<tr>
<td>Ferrario et al., 1995</td>
<td>Intra 0.97</td>
<td>Inter 0.98</td>
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<td></td>
<td>Inter 0.99</td>
<td>Intra 0.91</td>
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</table>

**Table 6.** Inter- and Intra-Measurer Estimates of Body Composition Measurement: Correlation Coefficient of Reliability and Technical Error of Measurement (TEM) from Published Studies

**Abbreviations:** WC: waist circumference; HC: hip circumference; WHR: waist-to-hip ratio; TEM: technical error of measurement; Inter: inter-measurer; Intra: intra-measurer; M: male; F: female.
pressure applied on subject’s body while measuring, difficulty in using the instruments and the accuracy in locating the exact point of measurement of the body part.\(^{(209)}\) For example, remaining in physical contact with subjects during application of the measuring tape may be difficult when subjects are oversized and measurers can over-manipulate the area to be measured.\(^{(96,212)}\) Human anthropometry requires specific manipulation especially in circumference measurements; to this end, researchers have suggested that training for measurers is necessary, including definitions of measuring location and proficiency in methods.

A tape measure is considered a routine health risk assessment tool for collecting circumference measurements. However the traditional methods of determining body shape are time consuming, prone to human error\(^{(211,213-215)}\) and show inter-measurer differences in measurements of the same subject.\(^{(210)}\) Multiple measurements must be performed under time constraints by interviewers, clinicians and researchers in a variety of settings and hence, negate the method’s value as simple and quick.\(^{(216)}\) To efficiently reduce anthropometric measurement deviations, researchers have begun to use 3D technology in this domain.\(^{(41,217)}\) The technology not only enhances the quality of length and circumference measurement but also provides detailed information on difficult-to-assess measurements such as body volume.\(^{(216-218)}\) Reliable 3D anthropometry is being substituted for the traditional tape measure to improve risk management of obesity-relevant diseases.\(^{(42-46)}\)

### Three-dimensional surface anthropometry

The results of traditional measurements are widely dependent on the measurer’s skill and measurement tools. Widely accepted techniques/tools are needed to measure multiple body sizes. A digitized optical method and computer to generate 3D photonic images of objects was developed decades ago, and has been used for whole-body surface anthropometric measurements in humans.\(^{(219)}\) A 3D scan requires only a few seconds and can be used on people with various body sizes without contact with the body.\(^{(44)}\) This method reduces human error and the data can incorporate computer-aided design and rapid prototyping.\(^{(41)}\) This newly developed, noninvasive, whole body imaging technology could be an important frontline tool in preventing, classifying and monitoring the treatment of diseases.\(^{(41,50,217)}\)

### Conclusions

This paper has reviewed the literature on the use of body anthropometry in the prognosis of the risk of MetS, CVD, CCa, PCa and BCa in a clinical setting. As a result, efficient assessment of the risk of these diseases is illustrated by the relationships among body measurements (BW, BH, WC and HC), indices (BMI, WHtR and WHR) and diseases in existing studies (as shown in the Fig. 1). WC has a high correlation with the risk of MetS and CCa, but remains controversial in CVD. Indices and composite measurements, generally perform better as follows: (1) the BMI shows a strong connection with CCa in men and young women; (2) the WHtR is generally accepted as a CVD predictor; (3) the WHR is strongly related to the risk of both MetS and CCa. Through cross-referencing the existing indices and measurements, researchers have identified a strong correlation between the WHR/WHR composite and MetS, whereas use of BMI/WC and BMI/WHR composites is still controversial in the prediction of CCa in women. On the other hand, body anthropometry still shows no consistent outcomes in correlation with PCa and BCa.

In conclusion, previous research has shown the great necessity of precise body measurements (especially in WC) and has brought attention to the following. (1) Latent issues such as deviations among existing indices. Individual differences in subjects in daily life (e.g. jobs, exercise and clothing) are also recognized variables affecting the efficiency of risk assessment. (2) Physical movement such as breathing (expansion and contraction of the rib cage and abdomen) could cause measuring deviation in different conditions (arm position, relaxed or tight posture).\(^{(96,218)}\) (3) Composite measurements may lower the chance of missed prognoses (especially in CVD) through cross-referencing body parts, but higher accuracy is required.\(^{(54,55,213,220)}\) (4) 3D technology has demonstrated reliable results, but still is not widely applied in the frontline of disease risk assessment.

### Acknowledgements

The author would like to thank Miss Judy Perry and Mrs. Judy Siirila for their revision of the manuscript and Dr. Jen-Der Lin for his assistance with the
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This research was supported by grants (NSC 89-2745-p-182-002) from the National Science Council of Taiwan, and Chang Gung Memorial Hospital (Contract No. CMRPG33008) and we thank them for financially supporting this research.

Appendices

The appendices, Table 1-6, are inserted in previous sections. In the appendices, the major references are compared with respect to demographics, fat measurements/indices and findings. The references were

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Fig. 1 Demonstration of the relationships among measurements, indices and diseases. Dark gray lines with black outlines indicate connections found in common by researchers; gray lines represent strong connections in certain demographic groups; lighter gray lines show connections still considered controversial; red thin lines demonstrate cross-reference connections. Abbreviations used: BW: body weight; BH: body height; WC: waist circumference; HC: hip circumference; BMI: body mass index; WHtR: waist-to-height ratio; WHR: waist-to-hip ratio; MetS: metabolic syndrome; CVD: cardiovascular disease; CCa: colon cancer; PCa: prostate cancer; BCa: breast cancer.
REFERENCES


Obesity-related diseases and anthropometry


95. Wang J. Waist circumference: a simple, inexpensive, and reliable tool that should be included as part of physical examinations in the doctor’s office. Am J Clin Nutr 2003;78:902-3.


100. Weissel RC. Body mass index as an indicator of obesity. Asia Pac J Clin Nutr 2002;8:681S-8S.


105. Dalton M, Cameron AJ, Zimmet PZ, Shaw JE, Jolley D, Dunstan DW, Welborn TA; AusDiab Steering Committee. Waist circumference, waist-hip ratio and body mass index and their correlation with cardiovascular...
of smoking, body mass, and physical activity with risk of prostate cancer in the Iowa 65+ Rural Health Study (United States). Cancer Causes Control 1997;8:229-38.


182. Morimoto LM, White E, Chen Z, Chlebowski RT, Hays


236. Shin A, Matthews CE, Shu XO, Gao YT, Lu W, Gu K,


肥胖相關代謝疾病及癌症的體表計測指數

楊朝陽 彭茜瑜 劉英傑 陳文誌 邱文科

代謝症候群、心血管疾病及部份癌症（如：結腸癌、攝護腺癌及乳癌）被認定為肥胖相關之疾病，肥胖形成期間多餘脂肪被儲存於人體不同部位並改變人體代謝及營養狀態。體表計測指數有助於該疾病的早期篩檢，其應用性、可信度及趨勢也被大量的討論，然而過去的研究並未有共識，例如：研究顯示腹圍尺寸，已廣為用於心血管疾病及結腸癌風險評量，但腹圍與代謝症候群卻需要更多證據，來證實與攝護腺癌及乳癌的關係性；經常被用來判斷肥胖的身體質量指數，對於男性及年輕女性結腸癌發生率有高度關連性，但在乳癌的發生率尚無一致發現。交叉比對各體表計測指數，發現腰圍高比及腰臀比可提高與這些疾病的聯結性，如：腰圍高比於心血管疾病、腰臀比於結腸癌，此概念被更進一步應用在複合指數探討，如腰圍高比與腰臀比間，有著對於亞洲人發生代謝症候群風險的關連性。最後，測量的準確度（包括工具及技巧）是影響疾病預測的重要因素，高精度的三次元人體測量技術，已逐步發展為預防醫學的輔助工具。(長庚醫誌 2011;34:1-22)

關鍵詞：肥胖，體表計測指數，代謝症候群，心血管疾病，癌症，量測誤差