Chapter 9

Measurement error of waist circumference: gaps in knowledge

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Abstract

Objective It is not clear whether measuring waist circumference in clinical practice is problematic because the measurement error is unclear, as well as what constitutes a clinically relevant change. This study summarizes what is known from state-of-the-art research.

Design To identify the magnitude of the measurement error of waist circumference measurements from literature, a search was conducted in Pubmed from 1975 to February 2011.

Results The measurement error may vary between 0.7 cm and 15 cm. Taking a realistic range of a measurable waist circumference into account (60-135 cm), we argue that a short-term clinically relevant change in waist circumference of 5% may lie between 3.0-6.8 cm and a maintained clinically relevant change of 3% between 1.8-4.1 cm.

Conclusions Based on these results, we conclude it may be difficult to distinguish clinically relevant change from measurement error in individual subjects, due to the large measurement error and unclear definition of clinically relevant change. More research is needed to address these gaps in knowledge. To minimize measurement error, we recommend using a uniform measurement protocol, training and repeated measurements.

Introduction

Clinical guidelines recommend physicians to base their obesity-related cardiovascular risk management on abdominal as well as general obesity (1;2). Abdominal obesity (as measured by waist circumference) has been conveyed as a better, independent, predictor of obesity related-disorders than general obesity (as measured by BMI)(3-5). The presence of abdominal obesity can thus indicate the need for interventions in subjects who would otherwise not be considered at risk based on general obesity alone (1). Measuring abdominal obesity using the waist circumference has been marked as feasible because it is easy to learn, takes no more time than measuring body height and weight, and requires minimal costs (6).
Waist circumference is now more often used to monitor changes as a result of interventions, not only by trained researchers but clinicians in primary care setting as well (7-9). However, physicians report they find it hard to measure (10-12). Moreover, studies showing good reliability of waist circumference measurements are mainly performed by health professionals trained in anthropometrics (1.3 to 6.5 cm) (13-15) while studies in which measurements are conducted by physicians show larger variability (0.7 to 12 cm) (16-18).

The consequences of variability for clinical practice are not clear yet. This depends on whether the variability is so large that clinically relevant changes within subjects or clinically relevant differences between subjects, cannot be measured reliably. Three problems can be identified here. First, only few reliability studies are available. Second, many studies report reliability (e.g., the intraclass correlation coefficient (ICC)), but not an absolute measurement error (e.g. in cm). This information is needed to interpret change scores in individual subjects in clinical practice (19). Third, it is not clear what a clinically relevant change in waist circumference is, because there is insufficient evidence on the dose-response relationship between reductions in waist circumference and obesity-related morbidity and mortality (11;20;21). Thus, it is necessary to summarize what is known from state-of-the-art research and identify gaps in knowledge. The aims of this study are therefore to 1) explain the difference between reliability and measurement error and highlight why it is important to determine the measurement error of waist circumference, 2) discuss what is known about the measurement error of waist circumference and which factors may cause this, 3) discuss what is known about clinically relevant changes in waist circumference, 4) discuss how knowledge about clinically relevant changes can help to interpret the magnitude and importance of the measurement error of waist circumference, and finally 5) provide recommendations for future research and clinical practice on the measurement error of waist circumference.

1. The difference between reliability and measurement error

The terms reliability and measurement error are part of the concept term ‘‘reproducibility’’, as both address whether measurement results are reproducible in test–retest situations (19). Reliability refers to how well subjects can be distinguished from each other in populations, despite the measurement error. This information is required for instruments that are used for discriminative purposes (e.g. to characterize individual differences between subjects in order to establish their clinical status and therapeutic needs, for example for discriminating between overweight and obese subjects). Measurement error assesses exactly how close values of repeated measurements within subjects are. This information is required for instruments that are used for evaluative purposes (e.g. to register change over time). The difference between reliability and measurement error is important for clinical practice because when studies present the reliability (e.g. ICC) of waist circumference measurements, a clinician is informed whether the instrument is able to discriminate between (for example overweight and obese) subjects in a sample. The clinician is not informed whether the instrument is suitable for monitoring waist circumference of individual subjects over time. In the latter case, the absolute measurement error around a single measurement of a single change score is important (19). This measurement error is expressed in e.g. the standard error of measurement or the limits of agreement (22). Moreover, measurement error provides an important advantage over reliability for clinical interpretation as it is expressed on the actual scale of measurement (e.g. cm), and not as a dimensionless value between 0 and 1. While information on both reliability and measurement error is necessary for clinical practice, reliability is generally high (15), but the magnitude of measurement error is not clear. In our article we focus on this absolute measurement error, which influences measurements in individual persons (22).

2. Measurement error of waist circumference

To identify the magnitude of the measurement error of waist circumference measurements from literature, a systematic search was conducted in Pubmed from 1975 to February 2011. Search terms for measurement error were selected from a search filter that was developed for finding studies on measurement properties (23), and combined with the text word 'waist circumference'. Studies using self-reported measurements and those among children or adolescents were excluded because these are associated with higher measurement error (15). Data were extracted on the Smallest Detectable Change (SDC) or Smallest Detectable Difference (SDD), which reflect the smallest change or difference in waist circumference of an individual subject that can be detected beyond measurement error (19). The search resulted in 559 studies, of which nine reported on the *intra*- or *inter*observer measurement error of waist circumference (e.g. repeated measurements on the same subjects by one observer, or by different observers, respectively) (Table 1). The methodological quality of studies was assessed by two authors (LV and CT) using the COSMIN checklist for grading studies on measurement properties (Box C, (24)). An overall methodological quality score was obtained by taking the lowest rating of the 11 items ('worst score counts') from the following ratings: excellent, good, fair or poor. For example, if for a study one item scored poor, the overall methodological quality of that study was rated as poor.

The selected studies included between 7-9279 participants, consisting of healthy adults, to employees or patients. The outcome assessors were physicians in three studies, and other health professionals in six studies. The outcome assessors were trained in advance in seven studies or between repeated measurements in two studies. All followed a standard (although different) protocol. Participants were measured in standing position, except for one study that measured participants in supine position. These measurements were carried out midway between the lower rib and iliac crest in five studies, as the narrowest point between the rib cage and iliac crest in one study and as the uppermost limit of the ileum in another study. One study examined the effect of measurement site (lower rib, iliac crest or midway) on the measurement error (25). Finally, the overall methodological quality of the studies was fair or poor.

Overall, the *intra*-observer measurement error varied from 0.7 cm to 9.2 cm. The *inter*-observer measurement error varied from 1.4 cm to 15 cm (Table 1). In most studies that measured both, the *intra*-observer measurement error was smaller (15). Moreover, smaller *intra*- and *inter*-observer measurement errors were found in larger studies. No notable differences were observed between participant characteristics, outcome assessor, measurement protocol, effects of training, or methodological quality, also in relation to the measurement error. However, greater measurement error was reported from measuring at the iliac crest or midway, compared to the lower rib, possibly because the latter is most easily located (25).

Based on the small number of studies and many differences between the studies, we conclude that it is difficult to draw conclusions on the magnitude of measurement error. Moreover, the variation in measurement error may be caused by a number of other factors not mentioned in Table 1 such as muscle mass, bone structure, lean tissues, looseness of abdominal muscles, posture, phase of respiration and time since last meal (26;27). Additionally, measurement error may be larger among overweight and obese subjects compared to normal weight subjects, due to difficulty in locating anatomical landmarks (14;15;27;28).

3. Clinically relevant change in waist circumference

Whether the measurement error is problematic in clinical practice can only be judged if there is a clear conception of the magnitude of change in, or difference between, waist circumference that is considered important. In other words, we need to identify a minimal important change (MIC) within subjects or minimal important difference (MID) between subjects in waist circumference (29). While several studies suggest that a reduction of waist circumference may be associated with benefits across a wide range of health outcomes, there is limited evidence for what constitutes a minimal important change or difference in waist circumference (30-33). The NIH stated in 1998 that a sustained reduction of 4 cm may be clinically relevant (34). More recently it has been suggested that, similar to body weight and BMI, a reduction in waist circumference of >5% may be considered a clinically relevant change for individual subjects on the short-term, and a maintained waist circumference of <3% from initial waist circumference may be considered clinically relevant for individual subjects on the long-term (35) (personal communication Dr. I. Lemieux, and Prof. Dr. R. Ross). No clear definitions were provided on what short-term change and long-term maintenance are (35).

Table 1. Studies reporting *intra-* or *inter-*observer measurement error of waist circumference measurements.

1st Author year (ref) Country	Design and Population	Outcome assessor and Training	Number of measurements and Protocol	Measurement site	Intra- and inter observer measurement error (SDC and SDD in cm)	Quality
Bosy-Westfahl 2010 (25) Germany	Cross-sectional 16 lean and obese adults	4 nutritionists. Well-educated and trained, regular comparison of results.	3 nonconsecutive measurements, one measurement per site Protocol: (1;38-40) Horizontal tape, after normal expiration, nonelastic plastic tape, standing, no compression of skin	a. Lowest rib (distal border) b. Iliac crest (superior border) c. Midway between both	Intra-observer a. 3.3 cm b. 6.1 cm c. 5.5 cm Inter-observer a. 6.7 cm b. 15.0 cm c. 14.1 cm	Poor
Dhaliwal 2009 (47) Australia	Cross-sectional 9279 subjects from the Australian Risk Factor Prevalence Study (1989). Aged 20-69 years, 93% Australian, UK, European and 5% Asian or African.	2 Observers (n=? at 8 survey sites). Trained.	2 consecutive measurements Protocol: (41;42) Horizontal tape, after full expiration, metal tape, no compression of skin, no clothing around the waist, front of subjects	Narrowest point between the rib cage and iliac crest	Intra-observer 1.8 cm (men) 1.7 cm (women)	Fair
Geeta 2009 (43) Malaysia	Cross-sectional 130 working adults at selected office setting (2005). Aged 18-64, mean age 36 (SD 11), 67% female, 83% Malaysian. Nonpregnant, ≥2 months postnatal, no physical disability or body deformation to stand upright.	2 public health nurses. Trained, unaware of objective, previous measurement blinded.	3 consecutive measurements Protocol: Clinical manual of NHMS III (45) Horizontal tape, after normal expiration, Seca S201 tape, front of subjects	Midway between lowest rib margin and iliac crest	Intra-observer 1.2 cm (lower and upper limits -1.1 to 1.3) Inter-observer 2.1 cm (lower and upper limits -1.9 to 2.3)	Fair
Nordhamn 2000 (14) Sweden	Cross-sectional 25 lean and 26 overweight (BMI<26 and BMI≥ 26) students, university staff and company employees, 50% men.	5 observers from the metabolic unit. Trained.	3 consecutive measurements, 1 measurement after 1-3 weeks Protocol: unknown Supine position	Midway between lower rib and iliac crest	Intra-observer ≈5.3 cm (all) ≈3.8 cm (lean) ≈6.4 cm (overweight) Intra-observer ≈2.5 cm (all) ≈3.2 cm (lean) ≈2.1 cm (overweight)	Fair

Panoulas 2008 (17) UK	Cross sectional 102 patients in an outpatient department of a hospital for the preliminary study, 28 new patients matched to 28 original patients for the clinical practice study (2006).	Preliminary study: 4 doctors, 4 nurses, 2 physiotherapists. Trained. Clinical practice: 3 medical students. Untrained and after written instructions.	Preliminary study: 3 measurements by the 9 other participants. Clinical study: ? Protocol: (39) During expiration, standard measuring tape, no clothing around the waist	Midway between the palpated lowest rib margin and iliac crest in the mid axillary lines	Preliminary study: Intra-observer 0.7 cm Inter-observer 1.4 cm Clinical study, untrained Inter-observer 2.6 cm (n=102), 2.5 cm (n=28) Clinical study, trained Inter-observer 3.3 cm (n=28)	Poor
Sebo 2008 (16) Switzerland	Cross-sectional 24 healthy adult volunteers. Mean age 41 (SD 14), 54% women, 21% overweight, 42% obese.	12 doctors. Untrained and after a 1 hour training (theory, demonstration, practice)	2 consecutive measurements by all 12 doctors, repeated after 1 week. Protocol: (3;44-46) Horizontal tape, end of normal expiration, standard measuring tape, standing, no clothing around the waist, no compression of skin	Midpoint between lowest rib and iliac crest	Inter-observer 12.0 cm (untrained) 7.2 cm (trained)	Poor
Sicotte 2010 (18) Canada	Cross-sectional 12 (at 3 months) and 7 other (at 18 months) HIV-patients in Mali (year unknown).	1 doctor, 2 health professionals, without prior experience. Trained, written instructions, practice every 2 weeks during 3 months.	2 times on 2 consecutive days by the same observer on 2 study occasions. Protocol: unknown Marks on location, horizontal tape, nonstrechable Gulick tape.	Uppermost limits of the ileum	Intra-observer 3.4 cm – 9.2 cm Inter-observer 5.5 cm - 6.5 cm	Poor
Ulijaszek 1999 (15) UK	Review 1. 2 studies between 1987 en 1995 2. 8 studies between 1987-1997	Health professionals	Not specified	Not specified	Inter-observer 1. 3.6 cm (2.8-4.4) Intra-observer 2. 6.5 cm (1.7-11.7)	Fair
Wang 2010 (28) Taiwan	Cross-sectional 76 participants from inpatient wards (year unknown). 33% men, mean age 47 (SD 14), underweight (n=5), normal (n=27), overweight (n=21), obese (n=23).	2 research assistants, without prior experience. Trained, instructions, 20 minute practice	2 times with 10 min. intervals Protocol: unknown Horizontal tape, end of normal expiration, inelastic plastic measuring tape, standing, feet apart and arms hanging freely.	Midpoint between lowest rib and iliac crest	Intra-observer 3.0 cm (all) 1.7 cm (underweight) 1.7 cm (normal), 2.2 cm (overweight) 4.7 cm (obese)	Fair

Following that recommendation, for an overweight woman with a waist circumference of 80 cm this corresponds with a waist reduction of at least 4.0 cm and a maintained waist circumference of at least 2.4 cm. For an obese woman with a waist circumference of 110 cm, this corresponds with a waist reduction of at least 5.5 cm and a maintained waist circumference of at least 3.0 cm. This shows that for subjects with a larger waist circumference, a larger reduction in waist circumference is necessary for change to be clinically relevant. Taking a realistic range of a measurable waist circumference, for example 60-135 cm, this implies that a short-term change between 3.0-6.8 cm and a maintained change between 1.8-4.1 cm may be clinically relevant.

4. The relation between measurement error and clinically relevant change

In order to distinguish clinically relevant change from measurement error, the measurement error (SDC) should be smaller than the clinically relevant change (MIC) (Figure 1a, adapted from (29)). In this case, changes as large as the clinically relevant change will be statistically significant (29). Thus, the smaller the measurement error, the smaller the changes that can be detected beyond measurement error. But if the measurement error (SDC) is larger than the clinically relevant change (MIC), this change cannot be distinguished from measurement error (Figure 1b, adapted from (29)).

The range of measurement error presented in table 1 (0.7-15 cm) indicates that we are probably able to detect a short-term clinically relevant change of 4 cm (5% for a women of 80 cm) or 5.5 cm (5% for a women of 110 cm), as the *intra*-observer measurement error is smaller than 4 cm in all but one study. However, the probability to detect a long-term clinically relevant change of 2.4 cm (3% for a women of 80 cm) or 3 cm (3% for a women of 110 cm) is much lower, as the *intra*-observer measurement error is larger than 3 cm in more than half of the studies. Across the realistic range of waist circumference measurements (60-135 cm), many relevant short-term changes (between at least 3.0-6.8 cm) and maintained changes (between at least 1.8-4.1 cm) can probably not be distinguished from measurement error. Interestingly, the measurement error of waist circumference seems equally problematic for normal weight, overweight or obese subjects. Although the measurement error is larger among overweight or obese subjects, a larger reduction in waist circumference is also necessary to obtain a clinically relevant change.

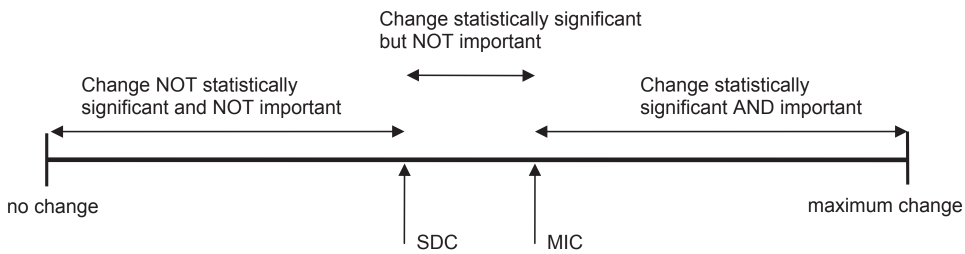

Figure 1a. Interpretation of change: the Smallest Detectable change (SDC) as a parameter of measurement error is smaller than the minimal important change (MIC)

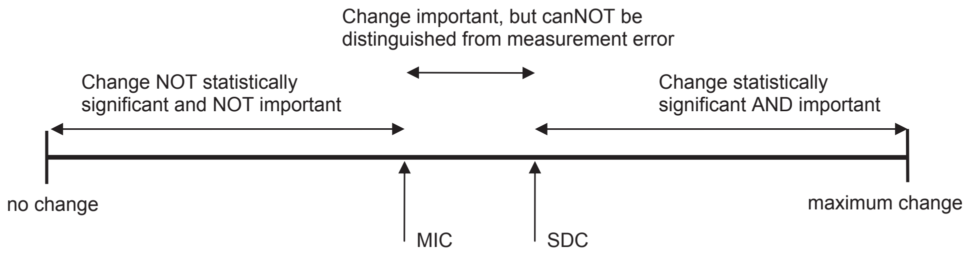

Figure 1b. Interpretation of change: the Smallest Detectable change (SDC) as a parameter of measurement error is larger than the minimal important change (MIC)

5. Recommendations for future research and clinical practice

To summarize, we have shown that there are two important gaps in knowledge. First, the assessment of measurement error identified a wide range (0.7-15 cm) of measurement errors, due to the small number of fair and poor quality studies, and many differences between studies. Second, no clear definition of clinically relevant change could be extracted from literature. Taking a realistic range of a measurable waist circumference (60-135 cm) into account, we argue that a proposed clinically relevant change in waist circumference of 5% at the short-term (approximately 3.0-6.8 cm) may be detectable, but a proposed maintenance of 3% (approximately 1.8-4.1 cm) may not be detectable, because it cannot be distinguished from measurement error. Although this paper does not provide practicing clinicians with empirical insight into the application and interpretation of waist circumference measurements in the clinical setting, the results do highlight that more attention should be paid to reducing measurement error, in order for clinicians and researchers to accurately measure real change in waist circumference rather than measurement error.

Three ways to potentially reduce measurement error in clinical practice are: 1) adopting a standard protocol, 2) training, and 3) repeating measurements (15). Two papers studied the influence of using different measurement protocols on waist circumference measurements. The first found that using different measurement protocol influenced the association between waist circumference, all-cause and cardiovascular disease mortality, cardiovascular disease and diabetes (36). These protocols however, were only compared on measurement site. The second study found that the type of protocol significantly influenced waist circumference measurements by comparing the measurement of waist circumference in 11 different ways (by anatomical site, posture, respiratory phase, and time since last meal) (27). However, as we have shown, other factors may also influence measurement error, and smaller measurement errors are required in order to detect (smaller) changes beyond measurement error. For clinicians, no standard protocol was advised as best. To overcome this gap in knowledge, we support the worldwide request for a uniform measurement protocol, decided on by an expert team (10;25;37;38).

A second way to reduce measurement error is by training. Measurement error is likely to be larger if measurements are carried out by poorly (often recently) trained individuals

(15). Training may thus reduce measurement error by quality control across time and by minimizing the number of observers (15). Unfortunately, it is unclear how (much) training is needed to decrease measurement error, nor whether the effect of training is sustained over time (16;17).
A third way to reduce measurement error is to repeat waist circumference measurements. If the same measurement is repeated for example two or three times, and the average value is taken, the measurement error of this average value is much smaller (by a factor √k with k being the number of repeated measurements) (39). For example, taking the realistic short-term (approximately 3.0-6.8 cm) and long-term (approximately 1.8-4.1 cm) clinically relevant change, two repeated measurements would result in an average measurement error of 2.1-4.8 cm for short-term clinically relevant change and 1.3-2.9 cm for long-term clinically relevant change. Three repeated measurements would result in an average measurement error of 1.7-3.9 cm for short-term clinically relevant change and 1.0-2.4 cm for long-term clinically relevant change. Thus, two measurements seem to be sufficient for detecting short-term changes, but three measurements seem to be necessary to distinguish long-term change from measurement error.

In conclusion, four gaps in knowledge have been identified. First, the magnitude of measurement error in unclear. Second, the definition of clinically relevant change is unclear. We therefore caution clinicians and researchers when interpreting individual changes in waist circumference, as clinically relevant changes in waist circumference may not be distinguished from measurement error. Third, consensus is needed on adopting a uniform protocol. Fourth, there is a lack of knowledge on the effects of training. Considering these gaps in knowledge, it is clear that there is a need for more good quality research and for action. Until then, we recommend consistently using one standard protocol, quality control as part of training and minimizing the number of observers, outsourcing measurements to well-trained clinicians and repeating measurements at least two, but preferably three times. Ultimately, by reducing measurement error, smaller changes in waist circumference may be detected by clinicians beyond measurement error. This is necessary for accurately monitoring changes in waist circumference of individual subjects over time.

Reference List

(1) National Institute for Health and Clinical Excellence. Obesity: Guidance on the Prevention, Identification, Assessment and Management of Overweight and Obesity in Adult and Children. 2006. Report No.: NICE Clinical Guideline 43.

(2) Ministry of Health CTRU. Clinical Guidelines for Weight Management in New Zealand adults. Wellington: Ministry of Health; 2009.

(3) Assmann G, Cullen P, Jossa F, Lewis B, Mancini M. Coronary Heart Disease: Reducing the Risk: The Scientific Background to Primary and Secondary Prevention of Coronary Heart Disease. A Worldwide view. Arterioscler Thromb Vasc Biol 1999, 19:1819-1824.

(4) Lean ME, Han TS, Morrison CE. Waist circumference as a measure for indicating need for weight management. BMJ 1995 Jul 15;311(6998):158-61.

(5) Yusuf S, Hawken S, Ounpuu S, Bautista L, Franzosi MG, Commerford P, et al. Obesity and the risk of myocardial infarction in 27,000 participants from 52 countries: a case-control study. Lancet 2005 Nov 5;366(9497):1640-9.

(6) 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 Nov;78(5):902-3.

(7) Smith SC, Jr., Haslam D. Abdominal obesity, waist circumference and cardio-metabolic risk: awareness among primary care physicians, the general population and patients at risk--the Shape of the Nations survey. Curr Med Res Opin 2007 Jan;23(1):29-47.

(8) Pajak A, Szafraniec K, Janion M, Szpak A, Wizner B, Wolfshaut-Wolak R, et al. The impact of the Polish national Programme of Cardiovascular Disease Prevention on the quality of primary cardiovascular disease prevention in clinical practice. Kardiol Pol 2010 Dec;68(12):1332-40.

(9) Giorda CB, Guida P, Avogaro A, Cortese C, Mureddu GF, Corsini A, et al. Association of physicians' accuracy in recording with quality of care in cardiovascular medicine. Eur J Cardiovasc Prev Rehabil 2009 Dec;16(6):722-8.

(10) Mason C, Katzmarzyk PT. Variability in waist circumference measurements according to anatomic measurement site. Obesity (Silver Spring) 2009 Sep;17(9):1789-95.

(11) Lee SK. Should waist circumference be used to identify metabolic disorders than BMI in South Korea? Eur J Clin Nutr 2010 Nov;64(11):1373-6.

(12) Verweij LM, Proper KI, Hulshof CTJ *et al*. Process evaluation of an occupational health guideline aimed at preventing weight gain among employees. *J Occup Environ Med* **53,** 722-729.

(13) Moreno LA, Joyanes M, Mesana MI, Gonzalez-Gross M, Gil CM, Sarria A, et al. Harmonization of anthropometric measurements for a multicenter nutrition survey in Spanish adolescents. Nutrition 2003 Jun;19(6):481-6.

(14) Nordhamn K, Sodergren E, Olsson E, Karlstrom B, Vessby B, Berglund L. Reliability of anthropometric measurements in overweight and lean subjects: consequences for correlations between anthropometric and other variables. Int J Obes Relat Metab Disord 2000 May;24(5):652-7.

(15) Ulijaszek SJ, Kerr DA. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr 1999 Sep;82(3):165-77.

(16) Sebo P, Beer-Borst S, Haller DM, Bovier PA. Reliability of doctors' anthropometric measurements to detect obesity. Prev Med 2008 Oct;47(4):389-93.

(17) Panoulas VF, Ahmad N, Fazal AA, Kassamali RH, Nightingale P, Kitas GD, et al. The inter-operator variability in measuring waist circumference and its potential impact on the diagnosis of the metabolic syndrome. Postgrad Med J 2008 Jul;84(993):344-7.

(18) Sicotte M, Ledoux M, Zunzunegui MV, Ag AS, Nguyen VK. Reliability of anthropometric measures in a longitudinal cohort of patients initiating ART in West Africa. BMC Med Res Methodol 2010;10:102.

(19) de Vet HC, Terwee CB, Knol DL, Bouter LM. When to use agreement versus reliability measures. J Clin Epidemiol 2006 Oct;59(10):1033-9.

(20) Huxley R, Barzi F, Lee CM, Lear S, Shaw J, Lam TH, et al. Waist circumference thresholds provide an accurate and widely applicable method for the discrimination of diabetes. Diabetes Care 2007 Dec;30(12):3116-8.

(21) Tuan NT, Adair LS, Stevens J, Popkin BM. Prediction of hypertension by different anthropometric indices in adults: the change in estimate approach. Public Health Nutr 2010 May;13(5):639-46.

(22) de Vet HC, Terluin B, Knol DL et al. (2010) Three ways to quantify uncertainty in individually applied 'minimally important change' values. J Clin Epidemiol 63, 37–45.

(23) Terwee CB, Jansma EP, Riphagen II, de Vet HC. Development of a methodological PubMed search filter for finding studies on measurement properties of measurement instruments. Qual Life Res 2009 Oct;18(8):1115-23.

(24) Terwee CB, Mokkink LB, Knol DL et al. (2012) Rating the methodological quality in systematic reviews of studies on measurement properties: a scoring system for the COSMIN checklist. Qual Life Res 24, 651–657.

(25) Bosy-Westphal A, Booke CA, Blocker T, Kossel E, Goele K, Later W, et al. Measurement site for waist circumference affects its accuracy as an index of visceral and abdominal subcutaneous fat in a Caucasian population. J Nutr 2010 May;140(5):954-61.

(26) Misra A, Wasir JS, Vikram NK. Waist circumference criteria for the diagnosis of abdominal obesity are not applicable uniformly to all populations and ethnic groups. Nutrition 2005 Sep;21(9):969-76.

(27) Agarwal SK, Misra A, Aggarwal P, Bardia A, Goel R, Vikram NK, et al. Waist circumference measurement by site, posture, respiratory phase, and meal time: implications for methodology. Obesity (Silver Spring) 2009 May;17(5):1056-61.

(28) Wang CY, Liu MH, Chen YC. Intrarater reliability and the value of real change for waist and hip circumference measures by a novice rater. Percept Mot Skills 2010 Jun;110(3 Pt 2):1053-8.

(29) Terwee CB, Roorda LD, Knol DL, De Boer MR, de Vet HC. Linking measurement error to minimal important change of patient-reported outcomes. J Clin Epidemiol 2009 Oct;62(10):1062-7.

(30) Cardona-Morrell M, Rychetnik L, Morrell SL, Espinel PT, Bauman A. Reduction of diabetes risk in routine clinical practice: are physical activity and nutrition interventions feasible and are the outcomes from reference trials replicable? A systematic review and meta-analysis. BMC Public Health 2010;10:653.

(31) Berentzen TL, Jakobsen MU, Halkjaer J, Tjonneland A, Overvad K, Sorensen TI. Changes in waist circumference and mortality in middle-aged men and women. PLoS One 2010;5(9).

(32) Voruganti VS, Cai G, Klohe DM, Jordan KC, Lane MA, Freeland-Graves JH. Short-term weight loss in overweight/obese low-income women improves plasma zinc and metabolic syndrome risk factors. J Trace Elem Med Biol 2010 Oct;24(4):271-6.

(33) Stevens VJ, Obarzanek E, Cook NR, Lee IM, Appel LJ, Smith WD, et al. Long-term weight loss and changes in blood pressure: results of the Trials of Hypertension Prevention, phase II. Ann Intern Med 2001 Jan 2;134(1):1-11.

(34) National Institutes of Health. The Practical Guide to the Identification,Evaluation and Treatment of Overweight and Obesity in Adults. Bethesda: National Insitutes of Health; 2000. Report No.: publication no. 00-4084.

(35) Stevens J, Truesdale KP, McClain JE, Cai J. The definition of weight maintenance. Int J Obes (Lond) 2006 Mar;30(3):391-9.

(36) Ross R, Berentzen T, Bradshaw AJ, Janssen I, Kahn HS, Katzmarzyk PT, et al. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? Obes Rev 2008 Jul;9(4):312-25.

(37) Park JY, Mitrou PN, Keogh RH, Luben RN, Wareham NJ, Khaw KT. Effects of body size and sociodemographic characteristics on differences between self-reported and measured anthropometric data in middle-aged men and women: the EPIC-Norfolk study. Eur J Clin Nutr 2010 Dec 22.

(38) WHO Technical Report. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO Consultation. Geneva: WHO; 1999.

(39) WHO Technical Report. Physical status: the use and interpretation of anthropometry. Report of a WHO Consultation. 1995. Report No.: 854.

(40) Alberti KG, Zimmet P, Shaw J. The metabolic syndrome--a new worldwide definition. Lancet 2005 Sep 24;366(9491):1059-62.

(41) Alexander H, Dugdale A. Which waist-hip ratio? Med J Aust 1990 Sep 17;153(6):367-8.

(42) Boyle CA, Dobson A, Egger G, Benault SA. Waist-to-hip ratios in Australia: a different picture of obesity. Aust J Nutr Diet 1993;50:57-64.
(43) Geeta A, Jamaiyah H, Safiza MN, Khor GL, Kee CC, Ahmad AZ, et al. Reliability, technical error of measurements and validity of instruments for nutritional status assessment of adults in Malaysia. Singapore Med J 2009 Oct;50(10):1013-8.
(44) Lean ME, Han TS, Deurenberg P. Predicting body composition by densitometry from simple anthropometric measurements. Am J Clin Nutr 1996 Jan;63(1):4-14.
(45) National Health and Nutrition Examination Survey III (NAHNES III). Body Measurements (Anthropometry). Rockville, MD 20859: Westat Inc.; 1988.
(46) Health Canada. Canadian guidelines for body weight classification in adults. Ottawa, Canada: Health Canada Publications Centre; 2003.
(47) Dhaliwal SS, Welborn TA. Measurement error and ethnic comparisons of measures of abdominal obesity. Prev Med 2009 Aug;49(2-3):148-52.
(48) Streiner DL, Norman GR. Health measurement scales. A practical guide to their development and use. New York: Oxford University Press; 2008.