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Anthropometry – Assessment of Body Composition

Anthropometrie – Bestimmung von Körperkomposition

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Summary

› **Anthropometric measurements** are non-invasive and easily obtained measurements with a wide range of utility in both paediatric and adult populations, including athletes. They can be used to diagnose risk factors, enhance performance and help patients to assess improvement after treatment.

› **To enhance long-term patient outcomes,** an inter-professional team should work together to consistently obtain reproducible results that apply to clinical settings. Accurate serial measurements over time are the most important aspect of anthropometry for a reliable indicator of risk factors.

› **This will help identify at-risk individuals early,** help promote a healthy lifestyle, and enhance performance in athletes. Choosing the appropriate assessment method depends on aim, resources, population, and required accuracy.

KEY WORDS:
BMI, skinfolds, ultrasound, Waist-to-Height-Ratio (WHtR), waist circumference

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Introduction

Assessment of body composition can provide valuable information about one's general health, nutritional adequacy, bodily development, but also about (sports) performance. Anthropometric measurements are quantitative measurements of the body, for which non-invasive tools and methods exist. In the paediatric population, anthropometric values are used to determine development and health status of the child (12). In adults, such measurements can help to assess health and nutritional status, as well as potential risk factors for diseases, such as obesity (13). In athletes, assessing body composition plays a key role in monitoring performance and training routines, especially in weight class and aesthetic sports (1).

The main components of anthropometry are height, body weight (and thereby body mass index (BMI)), as well as body circumferences and measurements used to estimate one's body composition.

Accurate, regular anthropometric assessments can help identify underlying medical, nutritional, or social problems in children (3, 5) and adults. Body composition is an important health and performance variable, which is why in adults, anthropometric measurements are recommended at each visit to the physician in order to determine nutritional status and the risk of future disease. Further, in athletes, improved body composition has been associated with increased strength and cardiorespiratory fitness (15, 32).

Single, one-time assessments are non-advisable since accurate serial measurements over time are the most important aspect of anthropometry for a reliable indicator of risk factors. Depending on population and interest, different (more or less accurate) measurement methods exist to assess body composition. Those most relevant for the general population as well as athletes are outlined here.

Considerations for Anthropometric Measurements and Body Composition Analysis

In order to assess characteristics of the human body accurately, it is essential to use validated and reliable methods, best lined out in a standardised protocol, such as suggested by ISAK (International Society for the Advancement of Kinathropometry; 34). Further, it is crucial that only well-trained individuals perform such measurements and that the subject's physical and emotional well-being is not compromised at any time during the assessment. Therefore, the following aspects should be considered before any assessment, independent of method or equipment.

Considerations Before Anthropometric Assessments and Body Composition Analysis

- To insure privacy, measurements should be taken in a separate, private room or in a screened off area
- The option to be accompanied by a friend or parent should always be offered, especially when examining children
- Personal space should always be respected, which is why most measurements should be taken from the side
- Wherever possible, the person measuring the subject should have enough space to move around the subject easily and manipulate the equipment without hindrance. Too little space can lead to inaccurate measurements
- Equipment and the measurer's hands should be cleaned before and after any measurements are taken
- Cultural sensitivities and socio-cultural aspects of touching should be considered, including cultural believes in the matter of dress.

Anthropometric Measurement Methods

The most frequently used assessment methods including necessary equipment and field of use are described thereafter.

Height

A person's height is assessed using a stadiometer, which is ideally attached to the wall and the floor should be level and hard (34). Height is measured using the stretch method and defined as the "perpendicular distance between the transverse planes of the most superior point on the skull when the head is positioned in the Frankfort plane and the inferior aspect of the feet" (34). Therefore, the subject has to stand with closed heels, buttocks and upper part of the back touching the scale and the head levelled in the Frankfort plane (lower edge of the eye socket in the same horizontal plane as the notch superior to the tragus of the ear). When aligned, the highest point on the skull is used as reference for a person's height.

Body Weight

Body weight assesses a person's body mass using calibrated (electronic) scales. Regular and certified calibration of all scales is critical, as well as its tare before every use. When weighing, the subject stands on the centre of the scale distributing the weight evenly on both feet without support.

Since body weight displays circadian variation it is important to record the time measurements are taken.

Table 1

Weight status classifications on basis of Body Mass Index (BMI) (39)

WEIGHT STATUS	BMI (KG/M²)
Underweight	< 18.5 kg/m²
Normal weight	18.5 - 24.9 kg/m²
Overweight	≥ 25 kg/m²
Obesity	≥ 30 kg/m²

Body Mass Index (BMI)

The BMI is frequently used as a measure of adiposity. To calculate the BMI, body weight is set in relation to the subject's height (kg/m²). It is used for weight classification in large populations (39).

The BMI, however, is solely a relative measure of weight and does not take into account a person's individual composition of body mass from fat and muscle tissue, body shape, or gender. The cut-offs (table 1) also underestimate obesity risk in certain populations, such as elite athletes and body-builders. Therefore, BMI is insufficient as the sole means of classifying a person as obese or malnourished. Yet, to determine risk of obesity, BMI measurement is suggested for all persons two years or older. For children, age- and gender-specific BMI percentiles/z-scores are recommended (e.g. 24).

Mass Index (MI)

An alternative measure of relative body weight that considers the individual's sitting height (s) and thus, implicitly, the leg length, is referred to as the mass index (MI = 0.53 m/hs), with m being body weight and h= body height (1, 21). The BMI and MI are equal when the ratio of sitting height and body height s/h = 0.53 (1, 21). The WHO cut-offs for underweight, overweight, and obesity (21) can remain the same when replacing the BMI by the MI.

Circumferences

The most commonly measured girths are waist and hip circumference, which can be used to estimate body fatness. In order to assess circumferences accurately, a flexible, non-extensible tape, no wider than 7 mm, and ideally made out of steel should be used (34).

Waist Circumference

Waist circumference is measured at its narrowest point of the abdomen "between the lower costal border (10^{th} rib) and the top of the iliac crest, perpendicular to the long axis of the trunk" (34). Subjects stand with their arms folded across the chest, measurement is taken at the end of a normal expiration (end tidal). If there is no obvious narrowing, it should be measured at the mid-point between the lower costal border and the iliac crest.

Subjects with a waist circumference of ≥ 88 cm and ≥ 102 cm for women and men, respectively, are classed as abdominally obese (4); in children, age- and gender specific values are available (24). Waist circumference is recommended to be performed regularly in clinical practice (26). ›

Hip Circumference

To assess hip circumference, the tape is passed in a horizontal plane across "the buttocks at the level of their greatest posterior protuberance, perpendicular to the long axis of the trunk" (34). Subjects stand with their arms folded across the chest and the gluteal muscles relaxed.

Waist-to-Hip-Ratio (WHR) and Waist-to-Height-Ratio (WHtR)

As an indicator of health or the risk of developing diseases, waist-to-hip- (WHR) or waist-to-height-ratio (WHtR) can being calculated. WHR is determined as waist circumference divided by hip circumference. WHtR refers to the relationship between waist circumference and height. In contrast to the widely used BMI, those ratios are supposed to display body fat distribution and thus allow greater significance with regard to health relevance of being overweight (28).

Both ratios are used as an indirect measure to determine abdominal obesity, which is defined as a WHR of > 0.90 for men and > 0.85 for women (38), and a WHtR of ≥ 0.5 (independent of gender, 14). Higher values indicate a greater risk of obesity-related cardiovascular diseases (CVD; 17).

An increase of 1 cm in waist circumference is associated with a 2 % increase in risk of future CVD and an increase of 0.01 in WHR is associated with a 5 % increase in CVD risk (8). Whereas WHR has been found to be an effective predictor of mortality in older people (25), WHtR is to be used with care when examining children below the age of five (17, 36).

Body Composition Analysis

In order to assess body composition as a whole or in certain parts, there are reference methods with high levels of accuracy, as well as field methods that differ in validity as they often represent indirect measurement of body composition. Among the reference methods, multi-component models, specifically the 4-component model using measurements of body density (hydrodensitometry), total body water (via deuterium dilution method), and bone mineral (via dual energy X-ray absorptiometry (DEXA)), is the leading reference method for body composition analysis (1). DEXA measurement has the ability to simultaneously measure bone, lean, and fat mass status, which is crucial in the assessment of athletes suffering from Relative Energy Deficiency in Sport (RED-S) – a condition that affects bone health as well. Yet, DEXA use for assessment of whole body composition still suffers a lack of general reference data even creating difficulties when comparing results from different systems (31). Still, the use of (multiple) lab-based techniques is costly and time-consuming and thus impracticable for large studies (1), therefore, for practitioners more relevant field methods are described thereafter.

Hydrodensitometry and Air Displacement Plethysmography

Hydrostatic weighing is the current gold standard technique for measuring a person's body density. It measures the displaced volume of water in order to determine body density; body composition can be estimated thereafter. Air displacement plethysmography is a similar densitometric method based on the same principle – displacing volume of air, rather than water. This two-component model that assesses mass and volume and therefore an estimation of body density, provides an estimation of fat and fat-free mass (FFM). Both methods are highly reliable and valid (10) but require very expensive acquisitions and estimation errors can occur due to different hydration status and movement while being measured (especially for air displacement plethysmography).

Computed Tomography (CT) and Magnetic Resonance Imaging (MRI)

CT and MRI can quantify muscle mass and quality (9) as well as abdominal fat mass. Due to the different magnetic properties of water and fat-bound protons, MRI allows to assess lean and adipose tissue compartments. Thereby, cross-sectional areas of skeletal muscles at distinct anatomical landmarks can provide accurate surrogates of total skeletal muscle amount and therefore may be used to identify patients with low muscle mass (7). Aspects such as sarcopenia may not be sufficiently captured by conventional anthropometric measurements such as BMI or WHR, particularly in obese patients (7).

Abdominal adipose tissue is often assessed using MRI, including visceral adipose tissue mass (23). Exact pictures of subcutaneous adipose tissue however, are sometimes difficult to obtain, as image resolution can be too coarse if insensitive coils are used or (especially with obese patients) the field of view is not large enough to image the whole cross section (20). Thus, equations overcoming this are available (20). Therefore, MRI or a combination of CT and MRI can obtain adipose tissue measurements from routine diagnostic protocol with high correlation to MRI whole-body examination adipose tissue volumes (19). For the validated protocol in adult population, a single CT and MRI slice at the L2-L3 vertebral level is used (30) and recently, gender-dependent reference normative values of MRI-derived visceral and subcutaneous adipose tissue in children have been published (19).

Bioelectrical Impedance Analysis (BIA) and Fat-Free Mass Index (FFMI)

One estimate of body composition, especially muscle mass and body fat percentage, is bioelectrical impedance analysis (BIA), where weak electric current flows through the body in order to measure the voltage to then calculate impedance of the body. It is based on the assumption that a more muscular person also has more body water, which leads to lower impedance, which can then be used to estimate total body water and thereafter, fat-free mass (FFM). Thus, a fat-free mass index (FFMI; FFM/height2) can be calculated giving an estimate of health risk.

BIA can be more accurate if upper and lower body parts are utilised. Generally, BIA is accurate for measuring large samples, but is of limited accuracy for tracking individual body composition over a period of time, and not suggested for precise measurements of individuals (10). BIA equations and cut-off values are population and device-specific, therefore, results should always be interpreted with caution. Still, BIA can provide valuable data in athletes as a compliment to other techniques such as skinfolds, circumferences or air displacement plethysmography.

Measurements of Subcutaneous Adipose Tissue Skinfolds

The measurement of skinfold thickness is a widely used and simple approach to indirectly estimate body fat. Skinfolds provide linear measurements of a double layer of skin and underlying subcutaneous adipose tissue (SAT) in a compressed state (16). The reliability of this technique depends strongly on the skills of the observer and standardisation of the technique with precise measurement sites is essential (1).

ISAK developed a standard protocol with instructions for accurate site marking and skinfold measurement at eight body sites located on the trunk, arms, and legs (34).

Researchers and practitioners should be cautious of using population-specific equations to estimate body fat at the individual level (1, 18). The validity of such equations relies on

Table 2

Overview of assessment methods relevant for clinical practice in relation to purpose, resources, and population including available normative data.

METHOD / TECHNIQUE	PURPOSE OF APPLICATION	RESOURCES REQUIRED	POPULATION	NORMATIVE DATA
(Body) Mass Index Relative body weight	Large-scale studies, determine underweight/overweight/ obesity	Stadiometer, calibrated scale Trained observer	Suitable for all ages and sizes (age- and nation-specific values for children and different ethnic groups available)	Normative data available for adults (39) and children (24)
Waist Circumference Indicator central adiposity	Large-scale studies, determine central obesity	Stadiometer, steel tape Trained observer	Suitable for all ages and sizes (age- and nation-specific values for children available)	Normative data available for adults (4) and children (24)
Waist-to-Height-Ratio Indicator central adiposity	Large-scale studies, determine central obesity	Stadiometer, steel tape Trained observer	Suitable for adults and children aged 5 and above	Normative data available for the general population (14)
Fat-free Mass Index Relative body composition incl. body water and fat-free mass	Large-scale studies, determine underweight/overweight/ obesity	Stadiometer, BIA scales incl. software Trained observer	Suitable for all ages and sizes	No normative data available as cut-offs are device- and population specific
Magnetic Resonance Imaging Tissue layer thickness of skin, SAT, muscle	Individual and group-based fat patterning analysis, small and large-scaled studies, cross-sectional and longitudinal studies	Portable MRI device, semi-automated analysis software (e.g. ParametricMRI, US, www.parametricmri.com) Trained observer	Suitable for all ages and persons. Reduced accuracy in obese	Normative data available for adults (37) and children (19)
Air Displacement Plethysmography Body Composition incl. Fat-free Mass	Individual and group-based fat patterning analysis, small scaled studies, cross-sectional and longitudinal studies	BOD POD or PEA POD (for children), including software (Life Measurement, Inc, Concord, CA) Trained observer	Suitable for all ages and persons. Reduced practicability for obese. Reduced accuracy in (small) children	Normative data for different groups (e.g. 33)
Skinfolds SAT thickness including skin	Individual and group-based fat patterning analysis, small and large-scaled studies, cross-sectional and longitudinal studies	Calibrated skinfold caliper Trained observer	Suitable for all ages and persons.	Normative data for skinfold thickness sums available for different groups (e.g. athletes of different disciplines) and measurement sites (1,27)
Ultrasound Tissue layer thickness of skin, SAT, muscle	Individual and group-based fat patterning analysis, small and large-scaled studies, cross-sectional and longitudinal studies	Portable ultrasound device, semi-automated analysis software (e.g. Rotosport, Austria, www.rotosport.at) Trained observer	Suitable for all ages and persons ranging from very lean to obese	Preliminary normative data for sum of SAT in athletes and general (adult) population (2)

several assumptions: skinfolds need to be of constant compressibility; skin thickness is the same at all sites, fat fraction and patterning of SAT is constant; as is the ratio of external to internal adiposity (18). However, none of these assumptions hold true (6, 18). Instead, raw skinfold data can be used to assess adiposity and describe fat patterning. This includes recording individual skinfolds, the sum of skinfolds, the ratio of two skinfolds or groups of skinfolds, and computing average skinfold depth across a number of sites. These values can be used for comparisons of individuals with group data/population norms or for longitudinal assessment especially in athletes, where assumptions of constant density and proportions of the components of fat-free mass are highly questionable (18).

It must further be pointed out that skinfold measurements do not allow assessment of visceral adipose tissue, which is associated with greater health risks.

Ultrasound

A novel, non-invasive approach to directly measure uncompressed SAT using brightness-mode ultrasound imaging has been developed (22, 35) and applied to various populations including athletes (e.g., 21), overweight and obese adults (35), and children (e.g. 16). Using portable ultrasound devices, this method can be applied both in the field and in clinical settings.

This imaging technique captures skin, SAT, muscle fascia, and underlying muscle tissue at eight body sites representing the trunk, arms, and legs. It was standardised in cooperation with the IOC Medical Commission Research Group on Body Composition, Health, and Performance by site marking, imaging, and image evaluation (22). With this approach, SAT thickness can be measured with an accuracy not reached by any other methods and limited only by biological factors. Measurement reliability is the overall limiting factor of this approach (21). High reliability can be obtained when measurements are › performed in accordance with the standardized protocol and observers are well trained, as demonstrated in children, adults and across a wide range of SAT thicknesses (16, 21, 22, 35).

Using this technique, studies have shown that ultrasound measurements revealed differences in fatness between individuals and at the group level that were undetected by commonly used anthropometric measures such as the BMI (e.g. 16, 35).

The use of SAT thickness sums for comparisons between athletes is recommended and preliminary normative data for SAT thickness sums of the eight standard sites are available (2). As with skinfolds, visceral adipose tissue is not assessed with this approach.

Conclusion

The methods described in this brief overview do not cover the multitude of measurement techniques available for body composition analysis and focuses only on the most commonly used approaches applicable in the field setting. Therefore, no claim is made to completeness. Table 2 gives an overview of the aforementioned methods including application purpose and resources needed.

Those methods are non-invasive but there are situations in which the measurements might give inaccurate results or are impossible. In such situations these measurements can give alarming or falsely reassuring data and should avoided. Otherwise, regular, reoccurring measurements are specifically advised in order to identify potential health risks early.

Conflict of Interest

The authors have no conflict of interest.

References

(1) **ACKLAND TR, LOHMAN TG, SUNDGOT-BORGEN J, MAUGHAN RJ, MEYER NL, STEWART AD, MÜLLER W.** Current status of body composition assessment in sport. Sports Med. 2012; 42: 227-249. doi:10.2165/11597140-000000000-00000

(2) **ACKLAND TR, MÜLLER W.** Imaging method: ultrasound, in: Hume P, Kerr S, Ackland T (Eds.): Best practice protocols for physique assessment in sport. Springer, New York. 2018: 131-141.

(3) **AMERICAN ACADEMY OF PEDIATRICS.** Statement of Endorsement: Defining Pediatric Malnutrition. Pediatrics. 2013. Epub ahead of print. doi:10.1542/peds.2013-1284

(4) **ARDERN CI, JANSSEN I, ROSS R, KATZMARZYK PT.** Development of health-related waist circumference thresholds within BMI categories. Obes Res. 2004; 12: 1094-1103. doi:10.1038/oby.2004.137

(5) **CHILD HEALTH AND DISABILITY PREVENTION PROGRAM.** Health Assessment Guidelines, Guideline 4. California, 2016.

(6) **CLARYS JP, MARTIN AD, DRINKWATER DT, MARFELL-JONES MJ.** The skinfold: Myth and reality. J Sports Sci. 1987; 5: 3-33. doi:10.1080/02640418708729760

(7) **CRUZ-JENTOFT AJ, BAHAT G, BAUER J, BOIRIE Y, BRUYÈRE O, CEDERHOLM T, COOPER C, LANDI F, ROLLAND Y, SAYER AA, SCHNEIDER SM, SIEBER CC, TOPINKOVA E, VANDEWOUDE M, VISSER M, ZAMBONI M; WRITING GROUP FOR THE EUROPEAN WORKING GROUP ON SARCOPENIA IN OLDER PEOPLE 2 (EWGSOP2), AND THE EXTENDED GROUP FOR EWGSOP2.** Sarcopenia: Revised European consensus on definition and diagnosis. Age Ageing. 2019; 48: 16-31. doi:10.1093/ageing/afy169

(8) **DE KONING L, MERCHANT AT, POGUE J, ANAND SS.** Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies. Eur Heart J. 2007; 28: 850-856. doi:10.1093/eurheartj/ehm026

(9) **FARON A, SPRINKART AM, KUETTING DLR, FEISST A, ISAAK A, ENDLER C, CHANG J, NOWAK S, BLOCK W, THOMAS D, ATTENBERGER U, LUETKENS JA.** Body composition analysis using CT and MRI: intra-individual intermodal comparison of muscle mass and myosteatosis. Nature Sci Rep. 2020; 10: 11765. doi:10.1038/s41598-020-68797-3

(10) **FIELDS DA, GORAN MI, MCCRORY MA.** Body-composition assessment via air-displacement plethysmography in adults and children: a review. Am J Clin Nutr. 2002; 75: 453-467. doi:10.1093/ajcn/75.3.453

(11) **FOSBØL MØ, ZERAHN BO.** Contemporary methods of body composition measurement. Clin Physiol Funct Imaging. 2015; 35: 81-97. doi:10.1111/cpf.12152

(12) **FRYAR CD, GU Q, OGDEN CL, FLEGAL KM.** Anthropometric Reference Data for Children and Adults: United States, 2011-2014. Vital Health Stat 3. 2016; 39: 1-46.

(13) **GAVRIILIDOU NN, PIHLSGÅRD M, ELMSTÅHL S.** Anthropometric reference data for elderly Swedes and its disease-related pattern. Eur J Clin Nutr. 2015; 69: 1066-1075. doi:10.1038/ejcn.2015.73

(14) **GIBSON S, ASHWELL M.** A simple cut-off for waist-to-height ratio (0.5) can act as an indicator for cardiometabolic risk: recent data from adults in the Healthy Survey for England. Br J Nutr. 2020; 123: 681-690. doi:10.1017/S0007114519003301

(15) **HÖGSTRÖM GM, PIETILÄ T, NORDSTRÖM P, NORDSTRÖM A.** Body composition and performance: influence of sport and gender among adolescents. J Strength Cond Res. 2012; 26: 1799-1804. doi:10.1519/JSC.0b013e318237e8da

(16) **KELSO A, MÜLLER W, FÜRHAPTER-RIEGER A, SENGEIS M, AHAMMER H, STEINACKER JM.** High inter-observer reliability in standardized ultrasound measurements of subcutaneous adipose tissue in children aged three to six years. BMC Pediatr. 2020; 20: 145. doi:10.1186/s12887-020-02044-6

(17) **LEE CM, HUXLEY RR, WILDMAN RP, WOODWARD M.** Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. J Clin Epidemiol. 2008; 61: 646-653. doi:10.1016/j.jclinepi.2007.08.012

(18) **MARFELL-JONES M, NEVILL AM, STEWART AD.** Anthropometric surrogates for fatness and health, in: Stewart AD, Stutton L (Eds.): Body Composition in Sport Exercise and Health. Routledge, Abdingdon. 2012: 126-146.

(19) **MARUNOWSKI K, SWIETON D, BZYL W, GRZYWINSKA M, KASZUBOWSKI M, BANDOSZ P, KHRICHENKO D, PISKUNOWICZ M.** MRI-derived subcutaneous and visceral adipose tissue reference values for children aged 6 to under 18 years. Front Nutr. 2021; 8: 757274. doi:10.3389/fnut.2021.757274

(20) **MICHEL S, LINDER N, EGGEBRECHT T, SCHAUDINN A, BLÜHER M, DIETRICH A, DENECKE T, BUSSE H.** Abdominal subcutaneous fat quantification in obese patients from limited field-of-view MRI data. Sci Rep. 2020; 10: 19039. doi:10.1038/s41598-020-75985-8

(21) **MÜLLER W, FÜRHAPTER-RIEGER A, AHAMMER H, LOHMAN TG, MEYER NL, SARDINHA LB, STEWART AD, MAUGHAN RJ, SUNDGOT-BORGEN J, MÜLLER T, HARRIS M, KIRIHENNEDIGE N, MAGALHAES JP, MELO X, PIRSTINGER W, REGUANT-CLOSA A, RISOUL-SALAS V, ACKLAND TR.** Relative Body Weight and Standardised Brightness-Mode Ultrasound Measurement of Subcutaneous Fat in Athletes: An International Multicentre Reliability Study, Under the Auspices of the IOC Medical Commission. Sports Med. 2020; 50: 597-614. doi:10.1007/s40279-019-01192-9

(22) **MÜLLER W, LOHMAN TG, STEWART AD, MAUGHAN RJ, MEYER NL, SARDINHA LB, KIRIHENNEDIGE N, REGUANT-CLOSA A, RISOUL-SALAS V, SUNDGOT-BORGEN J, AHAMMER H, ANDERHUBER F, FÜRHAPTER-RIEGER A, KAINZ P, MATERNA W, PILSL U, PIRSTINGER W, ACKLAND TR.** Subcutaneous fat patterning in athletes: selection of appropriate sites and standardisation of a novel ultrasound measurement technique: ad hoc working group on body composition, health and performance, under the auspices of the IOC Medical Commission. Br J Sports Med. 2016; 50(1): 45-54. doi:10.1136/bjsports-2015-095641

(23) **NEELAND IJ, GRUNDY SM, LI X, ADAMS-HUET B, VEGA GL.** Comparison of visceral fat mass measurement by dual-X-ray absorptiometry and magnetic resonance imaging in a multiethnic cohort: the Dallas Heart Study. Nutr Diabetes. 2016; 6: e221. doi:10.1038/nutd.2016.28

(24) **NEUHAUSER H, SCHIENKIEWITZ A, SCHAFFRATH ROSARIO A, DORTSCHY R, KURTH BM.** Reference percentiles for anthropometric measures and blood pressure based on the German Health Interview and Examination Survey for Children and Adolescents 2003–2006 (KiGGS). Robert Koch Institute, Berlin, 2016.

(25) **PRICE GM, UAUY R, BREEZE E, BULPITT CJ, FLETCHER AE.** Weight, shape, and mortality risk in older persons: elevated waist-hip ratio, not high body mass index, is associated with a greater risk of death. Am J Clin Nutr. 2006; 84: 449-460. doi:10.1093/ajcn/84.2.449

(26) **ROSS R, NEELAND IJ, YAMASHITA S, SHAI I, SEIDELL J, MAGNI P, SANTOS RD, ARSENAULT B, CUEVAS A, HU FB, GRIFFIN BA, ZAMBON A, BARTER P, FRUCHART JC, ECKEL RH, MATSUZAWA Y, DESPRÉS JP.** Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity. Nat Rev Endocrinol. 2020; 16: 177-189. doi:10.1038/s41574-019-0310-7

(27) **SANTOS DA, DAWSON JA, MATIAS CN, ROCHA PM, MINDERICO CS, ALLISON DB, SARDINHA LB, SILVA AM.** Reference values for body composition and anthropometric measurements in athletes. PLoS One. 2014; 9: e97846. doi:10.1371/journal.pone.0097846

(28) **SCHNEIDER HJ, FRIEDRICH N, KLOTSCHE J, PIEPER L, NAUCK M, JOHN U, DÖRR M, FELIX S, LEHNERT H, PITTROW D, SILBER S, VÖLZKE H, STALLA GK, WALLASCHOFSKI H, WITTCHEN HU.** The predictive value of different measures of obesity for incident cardiovascular events and mortality. J Clin Endocrinol Metab. 2010; 95: 1777-1785. doi:10.1210/jc.2009-1584

(29) **SHARMA AK, METZGER DL, DAYMONT C, HADJIYANNAKIS S, RODD CJ.** LMS tables for waist-circumference and waist-height ration z-scores in children aged 5-19 y in NHANES III: association with cardio-metabolic risks. Pediatr Res. 2015; 78: 723-729. doi:10.1038/pr.2015.160

(30) **SHEN W, PUNYANITYA M, CHEN J, GALLAGHER D, ALBU J, PI-SUNYER X, LEWIS CE, GRUNFELD C, HEYMSFIELD SB, HESHKA S.** Visceral adipose tissue: relationships between single slice areas at different locations and obesity-related health risks. Int J Obes. 2007; 31: 763-769. doi:10.1038/sj.ijo.0803474

(31) **SHEPHERD JA, NG BK, SOMMER MJ, HEYMSFIELD SB.** Body composition by DXA. Bone. 2017; 104: 101-105. doi:10.1016/j.bone.2017.06.010

(32) **SILVA AM, FIELDS DA, HEYMSFIELD SB, SARDINHA LB.** Body composition and power changes in elite judo athletes. Int J Sports Med. 2010; 31: 737-741. doi:10.1055/s-0030-1255115

(33) **SOTUNDE OF, GALLO S, VANSTONE CA, WEILER HA.** Normative data for lean mass and fat mass in healthy predominantly breast-fed term infants from 1 month to 1 year of age. J Clin Densitom. 2020; 23: 264-270. doi:10.1016/j.jocd.2018.07.004

(34) **STEWART A, MARFELL-JONES M, OLDS T, DE RIDDER H.** International standards for anthropometric assessment. ISAK, Lower Hutt, New Zealand, 2011.

(35) **STÖRCHLE P, MÜLLER W, SENGEIS M, AHAMMER H, FÜRHAPTER-RIEGER A, BACHL N, LACKNER S, MÖRKL S, HOLASEK S.** Standardized Ultrasound Measurement of Subcutaneous Fat Patterning: High Reliability and Accuracy in Groups Ranging from Lean to Obese. Ultrasound Med Biol. 2017; 43: 427-438. doi:10.1016/j.ultrasmedbio.2016.09.014

(36) **TAYLOR RW, WILLIAMS SM, GRANT AM, TAYLOR BJ, GOULDING A.** Predictive ability of waist-to-height in relation to adiposity in children is not improved with age and sex-specific values. Obesity (Silver Spring). 2011; 19: 1062-1068. doi:10.1038/oby.2010.217

(37) **ULBRICH EJ, NANZ D, DAHLQVIST LEINHARD O, MARCON M, FISCHER MA.** Whole-body adipose tissue and lean muscle volumes and their distribution across gender and age: MR-derived normative values in a normal-weight Swiss population. Magn Reson Med. 2018; 79: 449-458. doi:10.1002/mrm.26676

(38) **WORLD HEALTH ORGANISATION.** Waist circumference and waist-hip ratio. Report of a WHO Expert Consultation. World Health Organisation, Geneva, Switzerland 2011.

(39) **WORLD HEALTH ORGANISATION.** Obesity: preventing and managing the global epidemic. Report of a WHO consultation. World Health Organ Tech Rep Ser 2000; 894: i-xii,1-253.