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Advanced Anthropometric and Body Composition Indices in Sports Science, Nutrition, and Health Assessment: A Systematic Review

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Advanced Anthropometric and Body Composition Indices in Sports Science, Nutrition, and Health Assessment: A Systematic Review

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Abstract

Anthropometric assessment is widely used in sports science, nutrition, and health evaluation as a practical and non-invasive method for analyzing body composition, physical performance, and metabolic health. This review aimed to synthesize current evidence regarding the role of anthropometric parameters in sports sciences, nutritional assessment, and health monitoring.

A comprehensive literature search was conducted across major scientific databases, covering publications from 2020 to 2026. The findings indicate that anthropometric variables such as body mass index (BMI), waist circumference, waist-to-height ratio (WHtR), skinfold thickness, body circumferences, fat mass percentage (FM%), fat-free mass index (FFMI), and skeletal muscle mass indicators are strongly associated with athletic performance, nutritional status, and cardiometabolic risk. In sports sciences, these measurements are widely applied for talent identification, training monitoring, and performance optimization. In clinical and nutritional contexts, they contribute to the assessment of obesity, sarcopenia, malnutrition, and metabolic disorders. Advanced indices such as Body Roundness Index (BRI), A Body Shape Index (ABSI), somatotype analysis, and Phantom Z-scores provide improved evaluation of body proportionality and fat distribution.

Despite their broad applicability, anthropometric methods present limitations related to measurement variability and population specificity. Therefore, combining anthropometric assessment with advanced body composition techniques is recommended to improve accuracy and individualized evaluation.

The future of anthropometric science is expected to evolve toward AI-driven digital assessment systems integrated with personalized medicine and population-specific predictive models, allowing highly accurate, real-time, and individualized evaluation of body composition, metabolic health, and sport performance across diverse populations.

Keywords: Anthropometry; body composition; sports science; nutritional assessment; physical performance; anthropometric indices; health assessment.

Introduction

In the field of sport sciences and nutritional sciences, anthropometric profiling plays a central role in estimating physical characteristics connected with athletic performances, training adaptation, and body composition optimization [1,2]. In this context, previous studies have reported that the changes in anthropometric variables are strictly associated with physical fitness, strength development, and sport-specific performance, support their importance in talent identification and athlete monitoring [3,4]. These anthropometric measurements, including body mass index (BMI), skinfold thickness, and body circumference are widely used as non-invasive, cost-effective tools for assessing growth, development, and body composition across different populations in anthropometric characterization [5,6].

Otherwise, the evaluation of nutritional status which is a key determinant of health and physical capacity is closely related to anthropometric measurements. Nutritional assessment using body composition indices such as BMI-for-age, weight-for-height, and fat percentage provides insight into undernutrition, overnutrition, and related health risks such as obesity and related cardiovascular diseases [7,8]. In adolescent and young adult populations, several studies have reported significant associations between nutritional status, dietary intake, and physical fitness levels, emphasizing the integrative role of nutrition in health and development [3,9].

Additionally, in health assessment works, Human body metrics are usually used to monitor cardiovascular disease risk, metabolic status, and physical ability. They are frequently combined with biochemical and physiological signs to provide a comprehensive and exhaustive evaluation of physical health status in both clinical and athletic populations [10,11]. For instance, standardized preparticipation evaluations in athletes incorporate Body size parameters and fitness assessments to ensure safe participation and to detect potential health risks [10].

Recent line of evidence also underscores the interrelationship between morphometric characteristics, physical activity levels, and health outcomes. In adolescents, significant associations have been observed between body composition, physical activity, and physical fitness, suggesting that anthropometric indices can serve as predictive indicators of overall health and functional capacity [12 10]. Similarly, in older adults, body composition assessments are used to monitor health decline, frailty, and nutritional deterioration over time [8,13].

Nevertheless, despite their widespread use, Body size parameters present some limitations, principally when used separately. For example, BMI alone does not differentiate between fat mass and lean mass, which may lead to misclassification of nutritional status and health risks [14]. Consequently, several current research advocate for the combined use of anthropometry with other assessment tools, such as bioelectrical impedance analysis and physical performance tests, to improve the accuracy of health and nutritional evaluations [15,16].

In light of these considerations, a multidisciplinary approach integrating anthropometric parameters, physical fitness, nutritional assessment, and health indicators is indispensable to better comprehend human performance, improving health outcomes and preventive care strategies. Thus, the purpose of the present review is to synthesize current knowledge on the used anthropometric parameters using in sport sciences, focusing on their role in nutritional status evaluation and physical health assessment. A structured literature search was conducted to identify and critically evaluate recent studies related to anthropometric parameters, body composition indices, and their applications in sports performance, nutrition, and health assessment.

Materials and methods

Review Design and Research Question

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. The review aimed to identify, synthesize, and critically evaluate the current evidence regarding anthropometric parameters and body composition indicators used in sports sciences, nutrition, and health assessment.

The review was guided by the following PICO-based research question:

Population (P): Athletes, physically active individuals, healthy adults, adolescents, and clinical populations.

Intervention/Exposure (I): Assessment using anthropometric parameters and body composition indicators.

Comparator (C): Traditional anthropometric measures (e.g., body mass index, body weight, waist circumference) or alternative body composition assessment methods.

Outcomes (O): Evaluation of body composition, nutritional status, physical performance, metabolic health, cardiometabolic risk, and health-related outcomes.

The primary research question was:

"What anthropometric parameters and body composition indicators are currently used and validated for assessing body composition, athletic performance, nutritional status, and health outcomes in sports and nutrition sciences?"

Information Sources and Literature Search Strategy

The Web of Science, PubMed, ScienceDirect, SpringerLink, MDPI, Wiley Online Library, and Taylor & Francis Online, and Scopus databases were searched to identify studies published between January 2020 and April 2026, and aimed to identify, analyze, discuss or measure anthropometric parameters, body size and physical performances.

The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to anthropometry, body composition, sports sciences, nutrition, and health assessment. The following search equation was used and adapted according to each database:

("anthropometric parameters" OR anthropometry OR "body composition" OR BMI OR "body mass index" OR WHR OR WHtR OR ABSI OR BRI OR VAI OR CI OR FFMI OR FFM OR FM% OR somatotype OR "body adiposity index" OR "fat mass" OR "fat-free mass" OR "skeletal muscle mass") AND ("sports science" OR athletes OR "physical performance" OR exercise OR nutrition OR health OR "health assessment" OR "metabolic health" OR "cardiometabolic risk")

In addition, the reference lists of relevant articles were manually screened to identify potentially eligible studies not retrieved through electronic database searches.

Eligibility Criteria

The inclusion and exclusion criteria applied for the selection of the studies in this review were established to ensure the relevance, methodological quality, and scientific consistency of the literature included in the analysis. Table 1 presents the detailed inclusion and exclusion criteria.

Table 1: The inclusion and exclusion criteria

Inclusion Criteria	**Exclusion Criteria**
Studies published between January 2020 and April 2026	Studies published before January 2020
Articles written in English	Articles published in languages other than English
Peer-reviewed publications	Conference abstracts, editorials, letters to the editor, commentaries, books, theses, and unpublished reports
Original research articles, systematic reviews, and meta-analyses	Duplicate publications

Studies evaluating anthropometric parameters, body composition indicators, nutritional assessment, sports performance, or health-related outcomes	Studies focused exclusively on biochemical, pharmacological, genetic, or molecular outcomes unrelated to anthropometry
Studies involving athletes, physically active individuals, adolescents, adults, older adults, or clinical populations	Animal studies, in vitro studies, and studies unrelated to anthropometric assessment
Studies reporting measurement methods, predictive equations, reference values, validation procedures, or health/performance outcomes	Studies with insufficient methodological information or unavailable full text

Study Selection Process

The study selection process was performed according to PRISMA 2020 recommendations.

All retrieved references were exported to Zotero reference management software. Duplicate records were identified and removed using both automated and manual procedures.

The screening process consisted of two sequential phases:

Title and Abstract Screening: Titles and abstracts were independently screened to assess their relevance to the review objectives according to the predefined eligibility criteria.

Full-Text Assessment: Potentially eligible articles were retrieved and evaluated in full text to confirm their eligibility for inclusion.

Any discrepancies encountered during the selection process were resolved through discussion and consensus.

A total of 855 records were identified through database searching. After removal of duplicates (n = 183), 672 records were screened based on titles and abstracts. At this stage, 373 records were excluded. Subsequently, 299 full-text articles were assessed for eligibility. Of these, 90 studies were excluded for the following reasons: not meeting inclusion criteria related to population, outcomes, or study design. Finally, 209 studies were included in the qualitative synthesis.

The study selection procedure is illustrated in the PRISMA flow diagram (Figure 1).

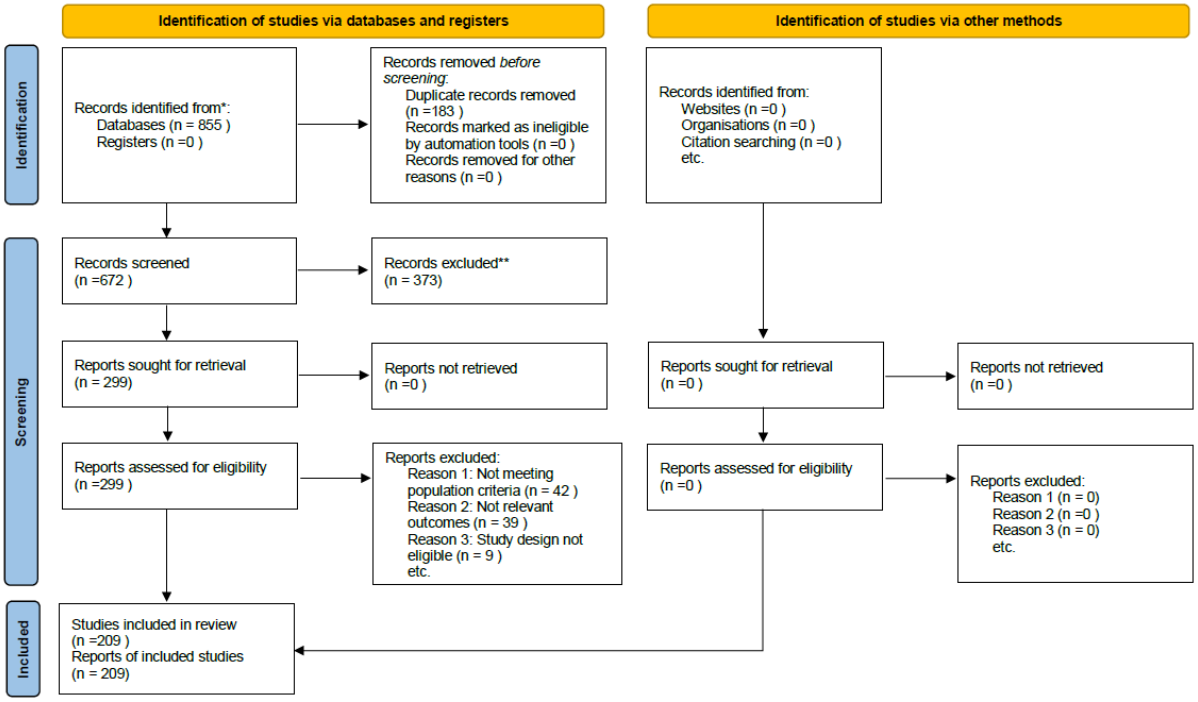


Figure 1: Summary of the search and screening methods implemented in this systematic review.

Data Extraction

Data extraction was performed using a standardized extraction form developed specifically for this review. The following information was collected from each eligible study: the author(s) and year of publication, country of study, study design, population characteristics, sample size, anthropometric parameters investigated, body composition indicators assessed, measurement techniques used, reference values and cut-off points, main outcomes related to physical performance, nutrition, metabolic health, and health assessment, as well as the principal conclusions reported by the authors.Methodological Quality Assessment and Risk of Bias

The methodological quality and risk of bias of the included studies were evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Tools, according to the study design.

Data synthesis

Data synthesis was conducted using a narrative systematic approach due to the substantial heterogeneity observed across the included studies in terms of study design, population characteristics, anthropometric indicators, outcome measures, and reporting methods, which precluded the performance of a quantitative meta-analysis. The selected studies were classified into several thematic categories, including traditional anthropometric indicators (body mass index, waist circumference, waist-to-hip ratio, and waist-to-height ratio), novel adiposity and cardiometabolic risk indices (body adiposity index, body roundness index, a body shape index,

visceral adiposity index, and conicity index), body composition parameters (body fat percentage, fat-free mass, fat-free mass index, and body mass fat ratio), and advanced anthropometric assessment methods such as somatotyping, Phantom Z-scores, and skeletal muscle mass indicators. The evidence was synthesized and critically interpreted according to measurement methodologies, reference values and cut-off points, validation procedures, and their applications in sports sciences, nutrition, physical performance evaluation, metabolic health, and general health assessment. This thematic synthesis facilitated the identification of methodological trends, strengths, limitations, and emerging perspectives in contemporary anthropometric research.

Results and Discussion

General Body Dimensions

Stature (Height) and Body Mass

Stature (height) is the vertical distance from the vertex of the head to the ground in an upright standing position, and represents a key anthropometric parameter for assessing growth, nutritional status, and overall health [17]. Stature is measured using a stadiometer under standardized conditions [17]. The stature can also be estimated by regression models based on alternative anthropometric parameters such as long bones, vertebral dimensions, or limb lengths [18].

Body mass corresponds to the total mass of the individual and integrates fat mass, lean mass, bone mass, and body water. In sport, it is interpreted in relation to stature and body composition. This parameter is measured using a calibrated digital or beam balance scale. Subjects wear light clothing and no shoes, and measurements are typically recorded to the nearest 0.1 kg under standardized conditions [1].

Arm Span

Arm span is the linear distance between the tips of the middle fingers when both arms are fully extended horizontally at shoulder level. It is a key anthropometric parameter widely used as a reliable proxy for stature, particularly in situations where direct height measurement is difficult or impossible [19]. Arm span is a stable body dimension, that have a strong positive correlation with height across different populations, making it highly valuable in clinical, nutritional studies [20].

Arm span is measured using a flexible or rigid measuring tape under standardized conditions. The subject stands upright with the back against a wall, arms extended laterally at shoulder height (90° abduction), elbows fully extended, and palms facing forward (Cherif et al., 2022). The measurement is taken from the tip of the middle finger of one hand to that of the opposite

hand, ensuring that both arms are aligned horizontally and symmetrically. The value is recorded to the nearest 0.1 cm. Arm span is frequently used in predictive regression models for estimating height and body mass index (BMI) across diverse populations (Oghenemavwe et al., 2024).

Body Circumferences (Girths)

Waist Circumference (WC)

Waist Circumference (WC) is the horizontal measurement of abdominal girth at a standardized anatomical level. It reflects central (visceral) adiposity, which is strongly associated with cardiometabolic risks such as type 2 diabetes, hypertension, and other metabolic syndromes. Also, WC provides a more accurate assessment of fat distribution, particularly abdominal fat accumulation [21,22].

The measurement of WC must follow a standardized protocol to ensure reliability. The subject stands upright with feet together, arms relaxed, and abdomen relaxed. A flexible, non-elastic measuring tape is placed horizontally around the abdomen at the midpoint between the lowest rib and the iliac crest , at the end of a normal expiration [23] or at the iliac crest level depending on the protocol. The tape should be snug but not compress the skin, and the measurement is taken at the end of a normal expiration. The value is recorded to the nearest 0.1 cm. Proper training of the assessor and consistency in anatomical landmarks are essential to minimize measurement variability [24,25]. Table 2 shows the Waist Circumference Cut-off Values

Table 2: Table: Waist Circumference Cut-off Values[22,26]

Category	Men (cm)	Women (cm)
Normal (low risk)	< 94	< 80
Increased risk	94 -101	80 -87
Substantially increased risk	≥ 102	≥ 88

Hip Circumference (HC)

This anthropometric parameter is defined as the maximum circumference measured around the buttocks at the level of the greatest gluteal protuberance. It reflects peripheral fat distribution and gluteofemoral muscle mass and is widely used in the assessment of body composition and cardiometabolic risk, particularly when combined with other indices such as the waist-to-hip ratio [27,28].

HC is measured according to standardized anthropometric protocols. The subject stands upright in a relaxed position, with feet together or slightly apart and body weight evenly distributed. A non-elastic measuring tape, preferably with constant tension, is placed horizontally around the hips at the level of the widest portion of the buttocks. The tape must be snug without compressing the soft tissues and maintained parallel to the floor. The measurement is typically recorded at the end of a normal expiration to ensure consistency. At least two measurements are taken, and the mean value is retained for analysis[29,30].

Standardized measurement conditions, including light clothing, proper posture, and a private examination setting, are recommended to minimize operator-dependent variability and improve measurement accuracy [29,31]. Table 3 resume the Standard Hip Circumference (HC) Values

Table 3: Standard Hip Circumference (HC) Values

Hip Circumference (HC) Context	Women (cm)	Men (cm)	Population / Interpretation	References
Elite soccer players	94.5-100.7	93.0-99.6	Elite athletes	[32]
General healthy adults	~90-100	~92-98	Normal adiposity distribution, lower cardiometabolic risk	[27,33,34]
Higher HC	>110	>105	Increased adiposity and obesity indices	[22,30]

Overall, anthropometric assessment begins with fundamental body dimensions such as stature, body mass, and arm span, which collectively form the basis for morphological and functional evaluation in sports science and health research [1,17].

Stature remains one of the most widely used anthropometric variables due to its strong association with genetic growth potential, skeletal development, and sport-specific performance advantages. It is particularly relevant in sports where leverage, reach, and biomechanical efficiency play a determining role, such as basketball and volleyball. However, its interpretation must consider biological variability and environmental influences, including nutrition and developmental conditions [35]

Body mass, when interpreted in isolation, provides limited information regarding body composition, as it integrates fat mass, lean mass, bone, and water compartments. Therefore, its relevance increases when combined with stature and body composition indicators to assess relative body size and performance potential[1].

Arm span has emerged as a reliable surrogate of stature, particularly in populations where direct height measurement is not feasible. Its strong correlation with height and relative stability across aging

processes make it useful in both clinical and sports contexts [19,20]. However, inter-individual variability suggests that population-specific regression models are required for accurate prediction.

These primary anthropometric dimensions represent the structural foundation for all derived indices. Nevertheless, their isolated use is insufficient for accurate physiological interpretation, which justifies the development of composite anthropometric indices.

Upper Arm Circumference (Relaxed and Flexed)

According to the International Society for the Advancement of Kinanthropometry (ISAK) standards, upper arm circumference is measured at the midpoint between the acromion and olecranon processes, previously identified and marked with the arm relaxed. In the relaxed condition (RUAC), the subject stands in the anatomical position with the arm hanging freely at the side, muscles fully relaxed. A non-elastic anthropometric tape is positioned perpendicular to the long axis of the arm at the marked midpoint, ensuring it is snug without compressing the soft tissues and remains horizontal. The measurement is recorded to the nearest 0.1 cm, typically in duplicate or triplicate, with the mean or median retained. This measure reflects total upper arm girth, integrating muscle, subcutaneous fat, and bone, and is widely used in sports science to monitor body composition and nutritional status [36–38].

In the flexed and tensed condition (FUAC), the subject raises the arm and flexes the elbow to approximately 90°, performing a maximal voluntary contraction of the biceps. The circumference is measured at the same anatomical level or at the point of maximal girth if slightly displaced during contraction, following standardized protocols.

The difference between flexed and relaxed values ($\Delta AC = FUAC - RUAC$) is often used in sports science as an indicator of muscle development and contractile capacity [39,40]. Furthermore, when combined with triceps skinfold thickness (TSF), MUAC allows estimation of muscle and fat compartments using equations such as $AMC = MUAC - (\pi \times TSF)$ and $UAMA = [MUAC - (\pi \times TSF)]^2 / (4\pi)$, which are widely applied to assess hypertrophy and training adaptations in athletic populations [37,41,42]. The table 4: indicates the Upper Arm Anthropometry Variables and standard values

Table 4: Upper Arm Anthropometry Variables

Variable	**Definition / Formula**	**Physiological Meaning**	**Normal Population**	**Athletes**	**References**
MUAC (Mid-Upper Arm Circumference)	Circumference at midpoint (acromion–olecranon)	Overall arm size (muscle + fat + bone)	Men: 25–32 cm | Women: 23–30 cm	Men: 30–38+ cm | Women: 26–34+ cm	[37,38]
RUAC (Relaxed Upper Arm Circumferenceà	Measured with arm relaxed	Baseline arm girth	Similar to MUAC	Slightly higher	[36]

				than normal	
FUAC ‘Flexed Upper Arm Circumferenceà	Measured with elbow at ~90° and biceps contracted	Maximum muscle girth	+1 to +3 cm vs RUAC	+3 to +6+ cm vs RUAC	[39,42]
ΔAC (Arm Circumference Difference)	FUAC − RUAC	Muscle contractility and functional development	1–3 cm	3–6+ cm	[40]
TSF (Triceps Skinfold Thickness)	Skinfold at triceps (mm)	Subcutaneous fat reserve	Men: 8–20 mm | Women: 15–30 mm	Men: 5–12 mm \	[43]

Thigh Circumference (TC)

Thigh circumference (TC) is commonly used to assess lower-limb muscle mass, fat distribution, and functional symmetry. This parameter is particularly valuable in clinical and sports settings for evaluating quadriceps muscle development, sarcopenia, rehabilitation progress, and musculoskeletal function [28,44] . In sports science, TC is also applied to monitor training adaptations and detect limb asymmetries, especially after injury or during recovery processes [45]

Thigh circumference is measured according to standardized anthropometric procedures. The subject stands upright with body weight evenly distributed and thigh muscles relaxed. A non-elastic flexible measuring tape is placed horizontally around the thigh, perpendicular to its longitudinal axis, ensuring that the tape fits snugly without compressing the soft tissues. Measurement sites may vary depending on the purpose of the assessment. In general anthropometry, the circumference is often measured at the mid-thigh, located halfway between the inguinal crease and the proximal border of the patella. In clinical and rehabilitation settings, a fixed-distance method, commonly 10 cm above the patella, is frequently preferred because of its high reproducibility [45,46]. To improve reliability, measurements are generally performed two or three times, and the mean value is recorded. The Thigh Circumference references values and interpretation are presented in Table 5.

Table 5: Thigh Circumference references values and interpretation

Category	Thigh Circumference (cm)	Interpretation	References
Low	< 50 (men) | < 45 (women)	Possible low muscle mass / sarcopenia risk, reduced functional capacity	[28]

Normal	50–60 (men) | 45–55 (women)	Typical general population values, reflecting balanced muscle and fat mass	[28,44]
Athletes	60–70+ (men) | 55–65+ (women)	Increased muscle development, adaptation to training stimuli	[44,45]
High-performance athletes	> 70 (men) | > 65 (women)	High muscle hypertrophy, typical in strength and power sports	[44]

Calf Circumference

Calf circumference (CC) is defined as the maximum girth of the lower leg, commonly used as a surrogate marker of skeletal muscle mass. It is particularly valuable in clinical and epidemiological settings for the assessment of sarcopenia, malnutrition, and functional decline, especially in older adults. Evidence shows that CC correlates positively with skeletal muscle mass, physical performance, and overall health outcomes, including morbidity and mortality risk [47–49]. Due to its simplicity, low cost, and non-invasive nature, CC is widely recommended when advanced body composition techniques such as DXA or BIA are not accessible [28,50].

The measurement of calf circumference is conducted by a flexible, non-stretchable measuring tape. The subject should be either seated with the knee at approximately 90° or standing with weight evenly distributed and muscles relaxed. The tape is placed horizontally around the calf at the point of maximum circumference, which is identified visually or by moving the tape along the calf to locate the largest girth. The measurement should be recorded to the nearest 0.1 cm without compressing the skin. It is generally recommended to measure the non-dominant leg and to take at least two readings to ensure reliability [47,49,51]. The Table 6 presents Calf Circumference Cut-off Values.

Table 6: Calf Circumference Cut-off Values

Population / Context	Cut-off value	Interpretation	References
Older adults (general)	< 31 cm	Indicative of low muscle mass / sarcopenia	[49]
Community-dwelling elderly	< 33–34 cm	Risk of malnutrition	[51]
Clinical screening (sex-specific)	Men: < 34 cm / Women: < 33 cm	Low skeletal muscle mass	[47]

Epidemiological studies	Population-specific thresholds	Predictor of mortality and adverse outcomes	[48,50]

Although circumferences are simple and cost-effective, their interpretative power significantly increases when corrected for adiposity (skinfolds), highlighting the importance of combined anthropometric modeling.

Bone Breadths

Biacromial Breadth

Biacromial breadth (BAB), also referred to as shoulder breadth, is a transverse anthropometric parameter defined as the maximum horizontal distance between the two acromial processes of the scapula. It represents the width of the shoulders and is widely used as an indicator of body frame size, upper body morphology, and physical performance potential. This parameter has been shown to correlate with stature, muscular development, and athletic performance in various populations, particularly in sports sciences and anthropometric profiling studies[52–54]. Additionally, biacromial breadth is considered a key skeletal dimension in evaluating body proportionality and is frequently included in models predicting body size and composition [55,56].

The measurement of biacromial breadth is performed using an anthropometer following standardized anthropometric procedures. The subject should stand upright in the anatomical position, with arms relaxed at the sides. The examiner palpates and identifies the lateral-most points of the acromion processes on both shoulders. The anthropometer branches are then placed horizontally across these points, ensuring that the instrument is perpendicular to the longitudinal axis of the body. The measurement is recorded to the nearest 0.1 cm, avoiding compression of soft tissues. This method ensures high reliability and reproducibility when conducted by trained personnel[57,58]. Table 7 show the Reference Values of Biacromial Breadth

Table 7: Reference Values of Biacromial Breadth

Population / Group	Mean ± SD (cm)	Interpretation	Reference
Adult males (general population)	38 – 42	Normal shoulder width	[53]
Adult females (general population)	34 – 38	Normal shoulder width	[53]

Male athletes (e.g., wrestlers)	40 – 45	Broad shoulders, athletic advantage	[58]
Volleyball female students	~39.6	Above-average shoulder breadth	[59]
Adolescent male swimmers	Higher than non-athletes	Associated with performance	[60]

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Bi-iliac Breadth

Bi-iliac breadth (BIB), also known as maximum pelvic breadth, is an important transverse anthropometric parameter defined as the maximum horizontal distance between the most lateral points of the iliac crests of the pelvis. It reflects pelvic width and is widely used in anthropometry, forensic science, and sports sciences to assess body proportions, sexual dimorphism, and body mass relationships. This parameter is strongly associated with overall body size and composition and is frequently included in predictive models of body mass and morphological variation [61,62]. Moreover, bi-iliac breadth is considered a key skeletal dimension in evaluating pelvic structure and has been linked to physiological and functional outcomes such as thermoregulation and locomotor efficiency [63,64].

The measurement of bi-iliac breadth is performed using a large sliding caliper or an anthropometer, following standardized anthropometric procedures. The subject stands upright with feet together and body weight evenly distributed. The examiner palpates the most lateral prominences of the iliac crests and places the caliper tips on these anatomical landmarks, ensuring proper alignment in the coronal (horizontal) plane. In some protocols, the caliper may be slightly angled (approximately 45°) to accurately capture the most lateral points of the pelvis. The measurement is recorded to the nearest 0.1 cm without compressing the soft tissues, ensuring accuracy, reliability, and reproducibility [65,66]. Reference Values of Bi-iliac Breadth are listed in Table 8.

Table 8: Reference Values of Bi-iliac Breadth

Mean ± SD (cm)	Population / Group	Interpretation	Reference
26 - 30	Adult males (general population)	Normal pelvic width	[61]
28 - 32	Adult females (general population)	Wider pelvis (sexual dimorphism)	[62]
22.02 ± ~2	Nigerian adult males	Population-specific mean	[67]

Variable (higher values)	Athletes (e.g., wrestlers/boxers)	Linked to performance traits	[58]
Moderate-high	Swimmers / handball players	Influences hydrodynamics/performance	[68]

Humeral Breadth

Humerus breadth (biepicondylar humerus breadth) is the distance between the medial and lateral epicondyles of the humerus, used to assess skeletal frame size, upper-limb robustness, and musculoskeletal development [69,70]. The humerus is a key long bone of the upper limb involved in force transmission and functional movement, making this measurement relevant in sports sciences, nutrition, and health assessment [71].

In sports contexts, higher humerus breadth values are generally associated with greater upper-body strength, throwing performance, and sport-specific skeletal adaptation, particularly in handball, climbing, wrestling, and combat sports [72,73]. In contrast, endurance athletes typically show moderate values reflecting balanced musculoskeletal development [74].

From a health and nutrition perspective, humerus breadth reflects bone robustness and body frame size, where lower values may indicate undernutrition, reduced physical activity, sarcopenia, or age-related bone loss, while higher values suggest better skeletal health and adequate nutritional status [75,76].

The measurement is performed using a sliding caliper with the elbow flexed at 90°, placing the instrument across the medial and lateral epicondyles, and recording the distance in cm or mm with high precision [69,77]. Standard values and interpretation of humerus breadth are indicated in Table 9.

Table 9: Standard values and interpretation of humerus breadth

Population	Values	Interpretation	References
Adult females	6.0-7.0 cm	Normal skeletal frame size; possible smaller frame or reduced musculoskeletal development	[69,76]
Adult males	6.8-8.0 cm	Typical male skeletal robustness and upper-limb strength	[76,78]

Power/strength athletes (wrestling, climbing, combat sports)	>7.5 cm	High skeletal adaptation due to chronic mechanical loading and strength demands	[72,78,79]
Handball / throwing athletes	>7.0 cm	Upper-limb power, throwing performance, and bone robustness	[73,80]
Endurance athletes (soccer, running)	6.5-7.5 cm	Balanced musculoskeletal development and lean body composition	[74,81]

Femoral Breadth

Femoral breadth, also referred to as biepicondylar femur breadth or femoral epicondylar breadth, is an anthropometric parameter defined as the maximum distance between the medial and lateral epicondyles of the distal femur. It represents the transverse width of the knee region and is widely used in anthropometry, sports science, and forensic studies to assess skeletal robustness, body frame size, and biomechanical characteristics. This measurement is strongly associated with physical performance, body composition, and skeletal geometry, and it is frequently used in studies involving athletes and clinical populations [82,83]. Femoral breadth is also an important variable in evaluating musculoskeletal development and can reflect differences in growth, nutrition, and training adaptations [84,85].

The measurement of femoral breadth is performed using a sliding caliper according to standardized anthropometric protocols. The subject is seated or lying supine with the knee flexed at approximately 90 degrees, allowing easy access to the distal femur. The examiner palpates the most prominent points of the medial and lateral epicondyles of the femur and places the caliper tips on these anatomical landmarks. The instrument is positioned perpendicular to the long axis of the femur to ensure accurate alignment. The measurement is recorded to the nearest 0.1 cm without compressing soft tissues, ensuring precision, reliability, and reproducibility [77,82]. Table 10 resume the Reference Values of Femoral Breadth

Table 10: Reference Values of Femoral Breadth

Population / Group	Standards values	Interpretation	Reference
Adult males (general population)	8 -10	Larger skeletal robustness	[85]

Adult females (general population)	7 - 9	Slightly smaller than males	[85]
Athletes (e.g., soccer, rugby)	Higher values	Associated with performance and strength	[86]
Adolescents / growing athletes	Variable	Reflects growth and maturation	[84]
Elite sports populations	Often increased	Adaptation to training loads	[83]

Globally, Bone breadths represent relatively stable anthropometric markers, less influenced by short-term training or nutrition, making them particularly useful for long-term morphological profiling[87].

Skinfold thickness

Skinfold thickness is a widely used anthropometric method for estimating body composition, particularly body fat percentage, in sports, clinical, and nutritional contexts. It is considered a practical and non-invasive field method, commonly applied using standardized calipers and validated equations to assess subcutaneous fat. Recent studies confirm its relevance and continued use in athlete monitoring and nutritional assessment, while also highlighting its strong agreement with reference methods such as multi-compartment models and DXA [88–91].

Moreover, skinfold thickness is a key tool in sports science for tracking training-induced changes in body composition and evaluating nutritional interventions, especially in elite and highly trained populations [92–94]. However, its accuracy depends on several factors including the evaluator's expertise, the choice of prediction equations, and the specific population studied, emphasizing the importance of standardized protocols and trained personnel [82,95]. Table 11 show Normative values of skinfold thickness in adults and athletes.

Table 11: Normative values of skinfold thickness in adults and athletes

Skinfold sum (mm)	Body fat (%)	Population	Interpretation	References
< 60-80 mm	5-12%	Elite male athletes	Very low / optimal for performance	[89,90]
70-100 mm	12-20%	Elite female athletes)	Low / optimal	[90,92]

60-120 mm	10-20%	Active adults (men)	Normal / healthy	[88,91]
90-150 mm	18-28%	Active adults (women)	Normal / healthy	[88,94]
120-180 mm	18-25%	General population (men)	Average	[82,95]
150–-mm	25-35%	General population (women)	Average	[82,93]
> 180-220 mm	> 25% (men) / > 35% (women)	Overfat / obesity risk	High adiposity / risk	[88,92]

In the study conducted by [96], the authors measured 10 skinfold using standard anthropometric calipers including, Triceps skinfold, Biceps skinfold, Subscapular skinfold, Suprailiac (iliac crest) skinfold, Abdominal skinfold, Mid-axillary skinfold, Chest (pectoral) skinfold, Thigh skinfold, Calf skinfold and Chin (submental) skinfold [96]

Furthermore, Skinfold thickness remains one of the most widely used field methods for estimating subcutaneous fat and total body fat percentage. Despite the emergence of advanced imaging techniques such as DXA and BIA, skinfold measurements remain highly relevant in sports science due to their practicality and cost-effectiveness[88,89]. However, accuracy is highly dependent on the evaluator expertise, site standardization and population-specific prediction equations. While skinfolds provide valuable longitudinal monitoring data, their limitations in obese and highly muscular populations require cautious interpretation.

Anthropometric Indices

Body mass index (BMI)

Body mass index (BMI) is a simple anthropometric index commonly used to classify underweight, normal weight, overweight, and obesity in epidemiological and clinical studies due to its simplicity, low cost, and practicality [97].

Body Mass Index (BMI) is calculated using the following equation:

$$\text{BMI} = \frac{\text{Body Weight (kg)}}{\text{Height}^2(m)^2}$$

According to the World Health Organization classification, BMI values are interpreted as follows: underweight (<18.5 kg/m²), normal weight (18.5-24.9 kg/m²), overweight (25.0-29.9 kg/m²), and obesity (≥30.0 kg/m²) [24].

Waist-to-Hip Ratio (WHR)

This anthropometric index is used to assess body fat distribution and central obesity. It is a key indicator of abdominal adiposity, as it reflects visceral fat accumulation, which is strongly associated with metabolic disorders such as diabetes, hypertension, and cardiovascular diseases. [98,99].

WHR is calculated using the following equation:

$$WHR = \frac{\text{Waist Circumference (cm)}}{\text{Hip Circumference (cm)}}$$

According to commonly accepted standards of the World Health Organization, WHR values indicating increased health risk are >0.90 for men and >0.85 for women. Values below these thresholds are generally considered within the normal range, whereas higher values are associated with elevated risks of obesity-related cardiometabolic complications in adults (Destra et al., 2023; Kułaga et al., 2023; F.-L. Zhang et al., 2021).

Waist-to-Height Ratio (WHtR)

The Waist-to-Height Ratio (WHtR) reflects central fat accumulation relative to stature and is considered a simple and sensitive indicator of health risk such as hypertension, diabetes, metabolic syndrome, and cardiovascular diseases, often outperforming BMI or waist circumference alone in predicting metabolic syndrome and cardiovascular diseases [100]. WHtR takes body stature into account and may provide better sensitivity for detecting central adiposity across different sexes and ethnic groups [101–103].

Both measurements are expressed in centimeters, and WHtR is obtained by dividing waist circumference by height [27,103].

$$\text{WHtR} = \frac{Waist\ Circumference}{Heigt}$$

Table 12 presents the Standard Values and Interpretation of WHtR in sport, nutrition and health assessment.

Table 12: Standard Values and Interpretation of WHtR

WHtR level	Population / Context	Interpretation in sport, nutrition & health	Key references
< 0.40	Lean athletic populations	Very low central fat; common in endurance athletes; high metabolic efficiency	[104]
0.40–0.49	Healthy adults / athletes	Normal fat distribution; optimal cardiometabolic profile	[102,103]
≥ 0.50	General population (cut-off)	Increased cardiometabolic risk (visceral adiposity, metabolic syndrome risk)	[105]
0.50–0.59	Overweight / recreational athletes with fat accumulation	Moderate abdominal obesity; reduced metabolic fitness	[104]
≥ 0.60	Obese / high-risk individuals	High cardiometabolic and cardiovascular risk	[105]

The Waist-to-Height Ratio (WHtR) is globally applicable indicator of central obesity, with strong predictive value for cardiometabolic outcomes such as hypertension and metabolic syndrome [105]. This makes it particularly useful in sports science, nutritional assessment, and public health screening. A widely accepted public health guideline recommends "keeping your waist circumference to less than half your height" [102].

Body Adiposity Index (BAI)

The Body Adiposity Index (BAI) is an anthropometric indicator used to estimate body fat percentage. It has been proposed as an alternative to BMI for evaluating body adiposity and metabolic risk, although its accuracy varies across populations [100,106,107].

BAI is calculated as follows:

$$BAI = \frac{Hip\ \text{Circumference (cm)}}{(Height(m)^{1.5}} - 18$$

BAI has shown moderate correlation with DXA-derived fat mass in different populations [33,108].

There is no universally standardized of BAI classification Values; however, recent studies commonly use the following interpretative ranges for adults (Table 13).

Table 13: Standard Values and Interpretation of BAI

Classification	Women (%)	Men (%)	References
Low adiposity	< 21	< 8	[106,107]
Normal range	21–33	8–21	[107,108]
Overweight	33–39	21–26	[100,107]
Obesity	> 39	> 26	[33,106]

BAI has been validated against DXA-derived body fat measurements and is used as a complementary index to BMI or WHR [100,109].

BRI (Body Roundness Index)

Body Roundness Index (BRI) is a novel anthropometric indicator developed to estimate body fat distribution and visceral adiposity using waist circumference and height. It provides a geometric estimation of body roundness and abdominal fat accumulation, making it a useful predictor of cardiometabolic risk and metabolic syndrome [110]. BRI has been shown to correlate strongly with visceral adipose tissue, insulin resistance, hypertension, and metabolic syndrome [111,112].

BRI is calculated using this mathematical formula:

$$BRI = 364.2 - 365.5 \times \sqrt{1 - \left(\frac{\left(\frac{\mathrm{WC}}{2\pi}\right)^2}{(0.5 \times H)^2} \right)}$$

where WC and H are expressed in meters [111].

Higher BRI values indicate greater abdominal adiposity and elevated cardiometabolic risk (Table 14). Several studies reported that BRI performs similarly or better than BMI and waist-to-height ratio for predicting metabolic syndrome and cardiovascular risk factors [112,113].

Table 14: Standard Values of Body Roundness Index (BRI)

BRI Value	Interpretation	Clinical Significance	Reference
< 3.41	Low body fat / underweight tendency	Low cardiometabolic risk	[111]
3.41-4.45	Normal adiposity	Healthy body fat distribution	[110]
4.46-5.46	Overweight	Increased abdominal fat accumulation	[114]

> 5.46	Obesity / high visceral adiposity	Elevated risk of metabolic syndrome and cardiovascular disease	[112]
≥ 6.0	Severe obesity risk	Strong predictor of insulin resistance and metabolic abnormalities	[111]

Visceral Adiposity Index (VAI)

The Visceral Adiposity Index (VAI) is a specific mathematical model used to estimate visceral fat distribution and adipose tissue dysfunction by integrating both anthropometric and metabolic parameters[106] , including waist circumference (WC), body mass index (BMI), triglycerides (TG), and high-density lipoprotein cholesterol (HDL-C). VAI is considered a practical surrogate marker of visceral adiposity and cardiometabolic risk in clinical nutrition, sports sciences, and epidemiological research [115,116]. It is particularly useful in sports and nutrition health because it reflects not only body fat accumulation but also metabolic alterations associated with insulin resistance and metabolic syndrome.

The VAI is calculated differently for men and women using the following equations:

For men

$$\text{VAI} = \left(\frac{WC}{39.68 + (1.88 \times BMI)}\right) \times \left(\frac{\text{TG}}{1.03}\right) + \left(\frac{1.31}{HDL}\right)$$

For women

$$\text{VAI} = \left(\frac{WC}{39.58 + (1.89 \times BMI)}\right) \times \left(\frac{\text{TG}}{0.81}\right) + \left(\frac{1.52}{HDL}\right)$$

Where:

- **WC** = waist circumference (cm)
- **BMI** = body mass index (kg/m²)
- **TG** = triglycerides (mmol/L)
- **HDL** = HDL-cholesterol (mmol/L)

Blood triglycerides and HDL-cholesterol are determined from fasting venous blood samples using biochemical assays [115,117].

VAI values close to **1.0** are considered metabolically healthy, whereas higher values indicate increased visceral fat accumulation and elevated cardiometabolic risk. In sports sciences and nutritional assessment, VAI is increasingly used to monitor metabolic health, body composition quality, and obesity-related risk among athletes and physically active populations [118,119] (Table 15).

Table 15: Standard Values of Visceral Adiposity Index (VAI)

VAI Value	Interpretation	Population/Context	Reference
< 1.0	Normal visceral adiposity and low metabolic risk	Healthy adults and athletic populations	[116]
1.0 - 1.9	Mildly increased visceral fat	General nutrition and sports health screening	[120]
≥ 2.0	Elevated visceral adiposity and increased cardiometabolic risk	Adults with overweight/obesity	[121]
≥ 2.5	High risk of metabolic syndrome and insulin resistance	Clinical and epidemiological studies	[117]
> 3.0	Severe visceral adiposity dysfunction	Sedentary or metabolically unhealthy adults	[122]
Lower values preferred in athletes	Indicative of better metabolic fitness and body composition	Sports sciences and military/athletic cohorts	[115,118,119]

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Body Shape Index (ABSI)

This is a novel anthropometric parameter developed to assess abdominal adiposity and body shape independently of BMI. ABSI standardizes waist circumference for height and weight, giving a better estimation of central obesity and cardiometabolic risk than BMI alone. Recent studies demonstrated that ABSI is associated with metabolic syndrome, cardiovascular risk factors, visceral adiposity, and mortality risk [123–125]. Additionally, [28] described ABSI as a waist-normalized anthropometric index reflecting body shape and central fat distribution.

ABSI is calculated according to the following equation [123]:

$$BSI = \frac{\text{Waist circumference (m)}}{BMI^{2/3} \times \text{height}^{1/2}}$$

Where:

- **WC** = Waist circumference (cm)
- **BMI** = Body mass index (kg/m²)
- **Height** = Height (m)

Lombardo et al., 2026 reported that ABSI is frequently multiplied by 1000 for easier readability in epidemiological studies [126].

Higher ABSI values (Table 16) indicate greater abdominal adiposity and increased cardiometabolic and mortality risk, even in individuals with normal BMI. Lower ABSI values are generally associated with lower visceral fat accumulation and healthier body shape profiles [124,125].

Table 16: Standard Values and Interpretation of ABSI

ABSI Value	Interpretation	Health Risk Level	Reference
< 0.075	Very low abdominal adiposity	Low cardiometabolic risk	[28,34]
0.075-0.079	Normal body shape	Average risk	[127]
0.080-0.084	Increased central obesity tendency	Moderate risk	[123]
≥ 0.085	High abdominal adiposity	High cardiometabolic and metabolic syndrome risk	[124,125]

In physically active and athletic populations, A Body Shape Index (ABSI) has been recognized as a complementary anthropometric tool that enhances the interpretation of body composition beyond traditional [128,129]. ABSI incorporates waist circumference, thereby providing a more specific estimation of central adiposity and fat distribution [128]. The added value of combining BMI with ABSI allows improvement of the assessment of obesity-related risk profiles, including metabolic dysfunction and cardiometabolic alterations [128,129].

In sports sciences, ABSI offers an interesting perspective because it provides information on central adiposity independently of BMI. This characteristic may improve the identification of athletes who present unfavorable fat distribution despite maintaining normal body mass values.

Nevertheless, the practical usefulness of ABSI in elite sports remains under investigation. Athletic populations often display body composition characteristics that differ substantially from those of the general population on which most ABSI reference values were established. Consequently, the interpretation of ABSI scores in athletes requires caution. Furthermore, current evidence suggests that ABSI should not replace traditional body composition assessments but rather complement existing anthropometric indicators within a comprehensive evaluation framework.

Conicity Index (CI)

The Conicity Index is an anthropometric indicator used to evaluate central obesity and cardiometabolic risk. It was developed to estimate the degree of abdominal fat accumulation based on waist circumference, body weight, and height. CI reflects the transition of body shape from a cylindrical form to a double-cone shape associated with visceral fat accumulation. Higher CI values indicate greater abdominal adiposity and increased cardiovascular and metabolic risk [100,108].

Recent studies demonstrated that CI is strongly associated with cardiovascular disease risk factors, metabolic syndrome, diabetes, frailty, and mortality, particularly in overweight, obese, and physically active populations [124].

The Conicity Index is calculated using waist circumference, body weight, and height according to the following equation[100]:

$$CI = \frac{\text{Waist circumference (m)}}{0.109 \times \sqrt{\frac{\text{Weight (kg)}}{\text{Height (m)}}}}$$

Where:

- **0.109** = Constant derived from body density assumptions

According to previous studies, CI values close to **1.0** indicate a normal cylindrical body shape [130] , whereas higher CI values (>1.25) indicate increased abdominal adiposity **Table 17**, which is associated with elevated cardiometabolic risk. CI is particularly useful in epidemiological studies examining central obesity [108]**.**

Table 17: Standard Values and Interpretation of CI

CI Value	Classification	Interpretation in General Health	Interpretation in Sports Sciences	References

< 1.00	Excellent / Optimal	Normal body fat distribution and Very low Cardiometabolic risk	Lean body composition, good abdominal fat control, and favorable athletic profile, endurance and well-conditioned athletes	[130,131]
1.00-1.10	Acceptable	Slight increase in abdominal adiposity, Low Cardiometabolic Risk	Acceptable body composition in recreationally active individuals; monitoring is recommended during nutritional follow-up	[100]
1.10-1.18	Moderate central adiposity	Beginning visceral fat accumulation and Moderate Cardiometabolic Risk	May negatively affect aerobic capacity, speed, agility, and recovery performance; suggests reduced physical fitness efficiency	[108]
1.18-1.25	High abdominal obesity	Significant central fat accumulation and High Cardiometabolic Risk	Decreased athletic performance, impaired movement efficiency, lower cardiovascular endurance, and increased fatigue during exercise	[124]
> 1.25	Severe central obesity	Excessive visceral adiposity and Cardiometabolic Risk	Poor physical conditioning, elevated inflammation, reduced muscular efficiency, and increased injury risk	[132]
> 1.30	Extreme abdominal obesity	Critical obesity level and Cardiometabolic Risk	Severe deterioration of sports performance and cardiometabolic health.	[133]

The Conicity Index is increasingly used in sports sciences to evaluate central fat distribution and its impact on physical performance. Lower CI values are generally associated with better aerobic fitness, improved agility, higher movement efficiency, and favorable body composition profiles in athletes.

Higher CI values may indicate excessive visceral fat accumulation. Also, CI is considered a useful complementary indicator to BMI because it better reflects abdominal adiposity and cardiometabolic stress [100]. Studies on soccer referees and active adults also showed that elevated CI is associated with reduced physical fitness and increased cardiovascular risk markers [131].

On the other hand, BMI remains the most widely used anthropometric index; however, it does not differentiate fat mass from fat-free mass, limiting its diagnostic precision in athletes [14]. Others indices such as WHR, WHtR, BRI, ABSI, and CI provide more precise estimations of visceral adiposity and cardiometabolic risk. Collectively, these indices outperform BMI in predicting cardiometabolic risk, reinforcing the shift toward multi-index evaluation frameworks.

Fat Mass Percentage (%FM)

Fat mass percentage (FM%) represents the proportion of total body mass composed of adipose tissue and is widely recognized as a major indicator of body composition, nutritional status, metabolic health, obesity risk, and physical performance [134]. Unlike Body Mass Index (BMI), FM% differentiates fat mass from fat-free mass (FFM), including muscles, bones, organs, and body water, thereby providing a more comprehensive assessment of body composition and health status [134]. In sports sciences and clinical nutrition, FM% is extensively used to monitor obesity, athletic performance, and cardiometabolic risk, with lower values generally associated with improved metabolic health and physical performance, whereas excessive adiposity is strongly linked to cardiovascular and metabolic disorders [135].

FM% can be estimated using several techniques, including anthropometric skinfold measurements, dual-energy X-ray absorptiometry (DXA), ultrasound imaging, and bioelectrical impedance analysis (BIA) [136]. In anthropometric assessment, predictive equations such as the Jackson and Pollock models estimate body density (Db) from the sum of skinfold thicknesses, after which Siri's equation is applied to calculate FM% [136]:

$$\mathrm{FM\%} = \left(\left(\frac{4.95}{Db}\right) - 4.50\right)\mathrm{X100}$$

where Db is the body density expressed in g/cm³. Although skinfold methods are inexpensive, practical, and suitable for field settings, their accuracy may vary according to sex, age, ethnicity, and training status[135,137]. DXA is considered one of the reference methods for body composition assessment because

it directly quantifies total and regional fat mass, including visceral adipose tissue [138,139]. In addition, ultrasound and BIA have emerged as reliable, non-invasive, and portable alternatives for evaluating body composition in both athletes and general populations [136,140,141]. Table 18 show Standard Values of Fat Mass Percentage (%FM).

Table 18: Standard Values of Fat Mass Percentage (%FM)

Sex	Population / Context	%FM Standard Values	Interpretation	References
Males	Very lean / elite athletes	6–13%	Essential fat to very lean athletic profile typical of elite performance athletes	[142]; [143]
	Male soccer players	8–15%	Competitive athletic range associated with high performance capacity	[76,144]
	Fitness / trained men	14–17%	Good metabolic health and optimal physical performance	[103,142]
	General adult men	18–24%	Acceptable adiposity	[143,145]
	Older adult men	>25%	Increased risk of sarcopenic obesity and metabolic dysfunction	Saito et al., 2022 [146]
Females	Female athletes	12–22%	Athletic range depending on sport type and training load	[147,148]
	Athletic / lean women	14–20%	Lean athletic profile commonly observed in trained women	[144,147]
	Fitness women	21–24%	Healthy fitness range associated with good metabolic status	[142]
	General adult women	25–31%	Normal adiposity range for general population women	[143,145]
	Obesity range (women)	≥32%	High fat mass associated with cardiometabolic risk	[149,150]
	Older adult women	>35%	Increased risk of frailty, metabolic syndrome, and functional decline	[151,152]

Fat-Free Mass (FFM)

Fat-free mass (FFM) includes all non-fat components of the body, such as skeletal muscle, bone, organs, and body water, and is a key determinant of strength and power performance [153]. It is commonly calculated as total body mass minus fat mass, or more specifically as body mass minus the sum of fat mass and bone mass [154]. FFM can also be assessed using advanced techniques such as fan-beam dual-energy X-ray absorptiometry (DXA), which provides accurate measurements of total and regional lean mass, including skeletal muscle mass [155].

To account for differences in body size, the fat-free mass index (FFMI) is used as a height-adjusted indicator, calculated as FFM (kg) divided by height squared (m^2). FFMI allows comparison across athletes by normalizing FFM relative to stature and is useful for classifying low, moderate, or high FFM levels in relation to performance and injury risk [156]. More recently, bioelectrical impedance-based predictive models have been developed using four-compartment reference models, showing good validity for estimating FFM in athletes [157]. However, despite variations in muscularity and musculoskeletal development, studies indicate that these factors do not significantly alter the density of FFM, supporting the general applicability of standard assumptions in body composition models [158].

Regarding reference values, FFMI in healthy adult populations typically ranges from 16-19 kg/m^2 in women and 18-22 kg/m^2 in men, while trained athletes present higher values depending on sport discipline. Resistance-trained male athletes often show FFMI values around 21–25 kg/m^2, with elite strength or power athletes occasionally exceeding 25 kg/m^2, whereas endurance athletes generally present lower values [156]. These values provide useful normative ranges for evaluating muscular development, performance potential, and training adaptation across populations.

Fat-Free Mass Index (FFMI)

Fat-Free Mass Index (FFMI) is a body composition indicator used to assess fat-free mass relative to height, providing a more accurate estimation of muscularity than Body Mass Index (BMI), particularly in athletic and physically active populations [159,160]. Fat-free mass includes skeletal muscle, bone, organs, and body water [161]. By normalizing lean mass to stature, FFMI allows valid comparisons across individuals with different anthropometric characteristics and sport disciplines [153,162]. It is widely used in sports science to characterize physique profiles, monitor training adaptations, and evaluate nutritional status, especially in strength, endurance, and mixed-sport athletes [159,160].

FFMI is calculated using the following equation [160]:

$$FFMI = \frac{\text{FFM (Kg)}}{Height^2(m^2)}$$

Fat-free mass (FFM) is commonly measured using bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry (DXA), skinfold anthropometry, or air displacement plethysmography [163]. Because it adjusts lean mass for height, FFMI provides a more robust assessment of muscularity than absolute FFM, particularly in athletes with heterogeneous body sizes and training backgrounds [164]. Consequently, FFMI is considered a reliable indicator for evaluating muscular development and monitoring nutritional and training adaptations in sport and clinical contexts [161,165].

FFMI reference values (**Table 19**) vary according to sex, training status, and sport discipline [153].

Table 19: Standard FFMI values and interpretation

FFMI (kg/m^2)	Body composition interpretation	Nutritional interpretation	Sportive interpretation	References
< 14 (women)	Very low lean mass	Possible chronic low protein/energy intake or undernutrition	Low functional capacity, high risk of reduced performance	[165]
14–16	Low lean mass (women)	Insufficient protein intake or low energy availability	Limited strength and endurance capacity	[166]
< 16 (men)	Very low lean mass	Inadequate dietary intake or sedentary lifestyle	Low muscular strength, poor athletic potential	[165]
16-17	Low muscularity	Marginal protein intake, low training stimulus	Below average strength and power	[164]
16.9-17.8	Average adolescent range	Normal growth-related nutritional status	Developing athletic performance	[167]
17-18.5	Average muscularity	Adequate diet but limited hypertrophy stimulus	Recreational performance level	[164]
18-20	Good muscular development	Adequate protein intake and balanced energy availability	Good general sport performance	[160]
18-21	Normal male range	Sufficient nutrition for maintenance of lean mass	Moderate athletic performance	[161]

19-24	Elite athlete range	High energy and protein intake supporting intensive training	High-level sport performance and adaptation	[153]
20-22	High muscularity	Optimized sports nutrition (protein + energy surplus)	Strong performance in power/speed sports	[159]
22-24	Very high muscularity	Structured nutritional periodization required	Elite strength and power performance	[162]
24-25	Excellent muscularity	High anabolic potential supported by advanced diet/training	Top-level resistance performance	[160]
> 25	Exceptionally high muscularity	Very high muscle accretion, rare in natural athletes	Maximum strength potential / elite physique athletes	[168]

In general, low values reflect insufficient lean mass and are often associated with low protein-energy availability and reduced physical performance capacity [165]. Moderate values indicate adequate nutritional status and recreational fitness levels, while higher values are typically observed in trained and elite athletes with optimized nutrition and training programs [156]. Very high FFMI values (>25 kg/m² in men) are rare and are often considered near the upper limit of natural muscularity in resistance-trained populations[168].

Body Muscle-to-Fat Ratio (BMFR)

The Body Muscle-to-Fat Ratio (BMFR) is a recent anthropometric and body composition index used to evaluate the balance between skeletal muscle mass and fat mass. It is used as a marker for assessing insulin resistance, metabolic syndrome, and cardiometabolic health [169]. BMFR reflects the physiological interaction between metabolically active muscle tissue and adipose tissue, where higher muscle mass contributes to improved glucose utilization and insulin sensitivity, whereas excessive fat accumulation is associated with chronic inflammation and metabolic dysfunction. BMFR is therefore increasingly recognized as a useful indicator in obesity research, sports sciences, and clinical nutrition [170].

BMFR is commonly measured using Bioelectrical Impedance Analysis (BIA) or other body composition assessment techniques such as dual-energy X-ray absorptiometry (DXA). It is calculated as the ratio between muscle mass and fat mass, either in kilograms or percentages:

$$BMFR = \frac{Muscle\ masspercentage\ (\%)}{Fat\ mass\ percentage\ (\%).}$$

Higher BMFR values (**Table 20**) generally indicate a healthier metabolic profile and better insulin sensitivity, whereas lower values are associated with sarcopenic obesity, insulin resistance, and increased cardiometabolic risk. Kurinami et al. (2025) proposed sex-specific cutoff values based on analyses against the hyperinsulinemic-euglycemic clamp method, suggesting that BMFR may serve as a practical and non-invasive screening tool for metabolic disorders.

Table 20: BMFR Standard Values

Sex	BMFR Standard	Interpretation
Male	≥ 2.75	Normal insulin sensitivity / favorable metabolic profile [170]
Male	< 2.75	Increased risk of insulin resistance
Female	≥ 1.65	Normal insulin sensitivity / favorable metabolic profile [170]
Female	< 1.65	Increased risk of insulin resistance

Cumulatively, Fat mass percentage (FM%), fat-free mass (FFM), and fat-free mass index (FFMI) provide deeper insight into metabolic and functional status. Higher FM% is associated with reduced metabolic efficiency and increased disease risk, whereas higher FFM and FFMI are linked to improved strength, power, and athletic performance[153,156] Unlike traditional indices, body composition indicators allow functional interpretation of anthropometric data, making them essential for performance monitoring in sport sciences.

Advanced Anthropometric Parameters

Somatotype (Heath-Carter Method)

The Heath–Carter somatotype is a standardized anthropometric method used to quantitatively describe human body shape through three independent components: endomorphy, mesomorphy, and ectomorphy [171,172]. It is considered the most widely used somatotyping method in sports sciences, nutrition, and body composition assessment [82]. The method evaluates the relative contribution of adiposity, musculoskeletal development, and body linearity to overall physique [173].

In the Heath–Carter system, endomorphy reflects relative fatness, mesomorphy represents musculoskeletal robustness, and ectomorphy indicates body linearity and slenderness [174]. Somatotype is expressed as a three-number rating such as *2–5–3*, corresponding respectively to endomorphy,

mesomorphy, and ectomorphy [172]. This method is widely applied in talent identification, sports performance evaluation, nutritional assessment, and health-related body composition studies [175,176].

The Heath–Carter somatotype method is based on 10 standardized anthropometric measurements performed according to the ISAK (*International Society for the Advancement of Kinanthropometry*) guidelines [177]. These measurements include body height, body mass, four skinfolds (triceps, subscapular, suprailiac, and medial calf), two bone breadths (humerus and femur), and two limb circumferences (flexed arm and calf girths) [171,178].

The endomorphy component is estimated from the sum of skinfold thicknesses corrected for height [172].

Mesomorphy is calculated using bone breadths, corrected limb girths, and stature measurements [173].

Ectomorphy is determined from the Height–Weight Ratio (HWR), which reflects body linearity [174]. The final somatotype is commonly represented on a somatochart to identify the dominant body physique category of the individual [82]. **Table 21** indicates Reference Values and Interpretation of Heath-Carter Somatotype.

Table 21: Reference Values and Interpretation of Heath-Carter Somatotype

Component	Reference values	Morphological interpretation	Interpretation in sport	Interpretation in nutrition and health
Endomorphy	< 2.5	Low relative fatness [171]	Advantage in endurance and speed sports [175]	Lower cardiometabolic risk [176]
	2.5–5.0	Moderate adiposity [172]	Common in mixed-sport athletes [174]	Generally balanced energy status [82]
	> 5.0	High adiposity [179]	May impair agility and endurance performance [171]	Increased obesity and metabolic disease risk [180]
Mesomorphy	< 3.0	Low musculoskeletal development [172]	Less favorable for strength and power sports [181]	Reduced muscle reserve [82]
	3.0–5.0	Moderate muscularity [173]	Suitable for polyvalent sports profiles [174]	Balanced body composition [176]
	> 5.0	High muscularity [171]	Advantage in sprint, combat, and power sports [181]	Better functional muscle status [82]

Ectomorphy	< 2.5	Low body linearity [172]	Compact physique profile [174]	May be associated with higher body mass [176]
	2.5–5.0	Moderate linearity [173]	Balanced athletic morphology [175]	Intermediate body composition profile [82]
	> 5.0	High body linearity [171]	Favorable for endurance and jumping sports [175]	Low fat and muscle mass relative to height [176]

Phantom Z-Scores (Ross Phantom Model)

The Phantom Z-score model (Ross Phantom Model) is a standardized anthropometric reference system utilized in the evaluation of body proportionality by expressing an individual's anthropometric measurements as deviations from a theoretical "phantom" human model (Ross & Wilson concept)[182]. This phantom represents a sex-independent reference body with fixed mean values for height, mass, skinfolds, circumferences, and bone breadths [182,183].

Phantom Z-scores indicate how many standard deviations an individual's measurement is above or below the reference population. A Z-score of 0 means the individual matches the phantom standard, while positive or negative values indicate greater or lower proportionality for a given anthropometric trait [32,184]. This method is widely used in sports science to compare athletes independently of age, sex, and body size [185,186]

The Phantom Z-score method is based on standard anthropometric measurements including skinfold thicknesses, body circumferences, bone breadths, body mass, and stature, obtained using ISAK protocols [32,183].

Each raw anthropometric variable is transformed into a standardized score using the Phantom model equation:

- The difference between the athlete's value and the phantom reference mean (phantom mean) is calculated.
- This difference is divided by the phantom standard deviation (Phantom SD).
- The result is the Phantom Z-score (Zp) for each variable.

Mathematical expression is:

$$Zp = \frac{(\mathrm{X} - \text{Phantom mean})}{\text{Phantom SD}}$$

where X is the athlete's measured anthropometric value [182].

The final interpretation allows the evaluation of body proportionality profiles, identifying whether an athlete has relatively higher or lower fat mass, muscle mass, or skeletal dimensions compared to the reference model (Monterrosa Qiuntero et al., 2023; Petri et al., 2024). Table 22 illustates the Phantom Z-score values and interpretation.

Table 22: Phantom Z-score values and interpretation

Anthropometric component	Phantom Z-score interpretation	Interpretation in sport	Interpretation in nutrition and health
Skinfolds (adiposity)	Z > 0 = higher fat; Z < 0 = lower fat [183]	Lower Z-scores are advantageous in endurance and speed sports [184]	Lower values indicate reduced adiposity and cardiometabolic risk [185]
Muscle-related girths	Z > 0 = greater muscular development [187]	High values indicate better performance in strength and power sports [32]	Reflects improved functional muscle mass and metabolic health [186]
Bone breadths	Z > 0 = larger skeletal frame [182]	Advantage in contact and power sports [32]	Indicates skeletal robustness and growth status
Body mass	Z > 0 = higher body mass than reference [183]	May be beneficial or limiting depending on sport type [185]	High values may suggest overweight risk
Stature (height)	Z > 0 = taller than phantom reference [32]	Advantage in basketball, volleyball, swimming [32]	Reflects linear growth and developmental status

Skeletal Muscle Mass Indicators

Skeletal muscle mass indicators derived from anthropometry provide indirect yet practical estimates of muscular development and are particularly relevant in strength- and power-oriented sports. These

indicators are widely used in both clinical and field settings because of their feasibility, portability, and low cost [5,188].

Anthropometric prediction models commonly rely on muscle girths corrected for subcutaneous adiposity through skinfold measurements, including arm, thigh, and calf circumferences. These corrected girths are incorporated into regression equations together with variables such as stature, body mass, age, sex, and ethnicity to estimate appendicular and total skeletal muscle mass [188,189]. Recent investigations have demonstrated that these anthropometric models present acceptable validity when compared with reference techniques such as dual-energy X-ray absorptiometry (DXA), particularly in healthy adults and athletic populations [189]. Nevertheless, the accuracy of these equations may vary according to population-specific factors, including ethnicity, training status, obesity, and age-related sarcopenia, emphasizing the necessity for population-adapted models [188].

The most commonly used skeletal muscle mass indicators in anthropometric and clinical assessment for identifying low muscle mass and sarcopenia in clinical and sport science contexts are the Appendicular Skeletal Muscle Mass Index (ASMI/SMI)**,** Appendicular Lean Mass (ALM)**,** Handgrip Strength (HGS)**,** and Gait Speed (GS)**** [190]. The Standard values and cut-off points for skeletal muscle mass indicators are listed in **Table 23**.

Table 23: Standard values and cut-off points for skeletal muscle mass indicators

Parameter	Men	Women	Reference
ASMI/SMI (DXA)	< 7.0 kg/m²	< 5.4 kg/m²	[191]
ASMI/SMI (BIA)	< 7.0 kg/m²	< 5.7 kg/m²	[191]
Handgrip strength	< 45 - 50 (pic) kg	< 27-30 (pic) kg	[192]
Gait speed	≤ 0.8 m/s	≤ 0.8 m/s	[193]
Appendicular Lean Mass (ALM)	< 20 kg	< 15 kg	[194]

In sports sciences and nutritional studies, skeletal muscle mass indicators are widely used as essential tools for evaluating body composition, athletic performance, and health status [188]. In this context, [195] reported that parameters such as skeletal muscle mass (SMM), appendicular skeletal muscle mass (ASM), lean body mass, and muscle thickness are commonly assessed using anthropometry, BIA, DXA, ultrasonography, magnetic resonance imaging (MRI), and emerging digital technologies. Moreover, muscle-related physiological indicators are valuable for monitoring training adaptation, muscle oxidative capacity, recovery, and exercise workload in athletes [196]. Recent technological advances, including smartphone-based prediction models, may improve accessibility for skeletal muscle mass evaluation outside specialized laboratories [197]. Additionally,

nutritional interventions and dietary supplementation strategies are closely associated with the preservation of lean muscle mass and functional performance during periods of muscle disuse [198]. Recent evidence also indicates that skeletal muscle assessment plays a critical role in identifying malnutrition, sarcopenia, and metabolic disorders while supporting nutritional planning and exercise prescription in both athletes and clinical populations [188].

Altogether, advanced anthropometric approaches provide a more comprehensive understanding of human morphology by integrating structural, proportional, and functional body composition characteristics. Unlike traditional anthropometric measurements, these models allow individualized evaluation of muscularity, adiposity, and body proportionality, thereby improving the precision of athlete profiling, training monitoring, and health risk assessment. Moreover, the integration of somatotype analysis, Phantom Z-scores, and skeletal muscle mass indicators contributes to the development of predictive and comparative frameworks applicable in sports sciences, clinical nutrition, and preventive medicine. Their growing use also reflects the evolution of anthropometry from a purely descriptive discipline toward a multidimensional and evidence-based approach for evaluating physical performance, metabolic health, and functional capacity across populations.

Discussion

Despite their widespread use in sports science, nutrition, and public health, anthropometric parameters and body composition indices present several methodological and practical limitations that should be considered when interpreting results. Although these measurements are inexpensive, non-invasive, and easy to perform, their predictive accuracy varies according to age, sex, ethnicity, training status, and physiological characteristics of the population under investigation [199]; [200]).

Body mass index (BMI) remains one of the most commonly used anthropometric indicators because of its simplicity and applicability in large-scale epidemiological studies. However, BMI does not distinguish fat mass from lean body mass and may therefore misclassify highly trained athletes as overweight or obese due to increased muscularity rather than excessive adiposity ([199]. Furthermore, BMI provides no information regarding fat distribution, a key determinant of cardiometabolic risk [201].

Circumference-based measurements including waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) offer additional information regarding central adiposity and cardiometabolic health. Nevertheless, these measurements remain sensitive to anatomical landmark identification, measurement technique, breathing phase, and postural

variations, which may affect reliability and reproducibility [200,202]. Moreover, cut-off values often differ among ethnic groups and populations, limiting the universal applicability of currently available reference standards [203].

Additionally, the accuracy of Skinfold thickness is strongly dependent on evaluator expertise, caliper quality, and the prediction equations employed (Lewandowski et al., 2022; [200]). Prediction equations developed in one population may not be transferable to other ethnic groups, age categories, or athletic disciplines, potentially leading to systematic estimation errors [202]. Also, skinfold measurements become increasingly challenging in individuals with severe obesity and may underestimate visceral adiposity, which has important clinical implications [201].

As regarding to breadth measurements, such as humeral and femoral breadths, provide useful information regarding skeletal frame size and somatotype classification. Nevertheless, these measurements require strict standardization and experienced evaluators to ensure reliability. Small errors in landmark identification may significantly affect skeletal proportionality indices and subsequent body composition estimations [200].

Similarly, body composition indices such as the Fat-Free Mass Index (FFMI), Body Roundness Index (BRI), Conicity Index (CI), A Body Shape Index (ABSI), and Visceral Adiposity Index (VAI) have been developed to overcome some of the limitations of traditional anthropometric measures. While these indices often demonstrate stronger associations with cardiometabolic risk factors than BMI alone, their interpretation remains challenging because population-specific reference values are still evolving and consensus regarding optimal cut-off points has not yet been fully established [199,201].

Another important limitation of anthropometric assessment is its inability to directly quantify tissue composition. Anthropometric measurements provide indirect estimations of body compartments and may not accurately reflect regional fat distribution, intramuscular adipose tissue accumulation, hydration status, or muscle quality [204,205]. Consequently, discrepancies may arise when anthropometric estimates are compared with reference techniques such as dual-energy X-ray absorptiometry (DXA), magnetic resonance imaging (MRI), or advanced bioelectrical impedance analysis (BIA) methods [204].

Future developments in anthropometric science are expected to focus on the integration of digital technologies, artificial intelligence, and machine learning algorithms into body composition assessment [206]. Advances in three-dimensional body scanning, computer vision systems, and wearable technologies may facilitate rapid, non-invasive, and highly standardized

measurements in both clinical and sports settings [207,208]. Artificial intelligence-based image analysis has the potential to improve body composition prediction by combining anthropometric data with movement patterns, physiological markers, and performance metrics [206].

Furthermore, future research should prioritize the development of population-specific predictive models that account for age, sex, ethnicity, biological maturation, and athletic specialization [199,203]. Such approaches may improve the accuracy and applicability of anthropometric assessments while supporting personalized nutrition, precision medicine, and individualized training interventions. The integration of anthropometric, physiological, biochemical, and omics-derived data is likely to represent the next stage in body composition research, providing more comprehensive tools for health monitoring, injury prevention, and performance optimization in both athletic and clinical populations [201].

Future Perspectives

Future developments in anthropometric assessment are expected to focus on improving measurement accuracy, standardization, and personalization through the integration of emerging technologies and advanced analytical approaches. Although traditional anthropometric methods remain widely used because of their simplicity, low cost, and field applicability, they are inherently limited by measurement error, operator dependency, population-specific variability, and their inability to directly assess tissue composition [199,200,202].

One of the most promising directions involves the integration of digital technologies into body composition assessment. Recent advances in wearable devices, digital monitoring systems, and portable assessment tools are creating new opportunities for continuous and real-time evaluation of morphological and physiological characteristics in both athletic and clinical populations [207,208]. Such technologies may facilitate longitudinal monitoring of body composition changes while reducing some of the limitations associated with conventional anthropometric measurements.

Artificial intelligence, machine learning, and computer vision technologies are also expected to play an increasingly important role in sports science and body composition research. These approaches have demonstrated considerable potential for processing large datasets, identifying complex relationships among anthropometric variables, and improving predictive modeling of health and performance outcomes [206]. The integration of artificial intelligence with

anthropometric assessment may contribute to more objective, automated, and individualized evaluations while minimizing observer-related variability.

Future research should also prioritize the development of population-specific prediction models. Current anthropometric equations and reference standards are frequently derived from specific populations and may not be fully applicable across different ethnicities, age groups, sexes, or athletic disciplines [199,209]. Consequently, the establishment of updated normative databases and population-specific predictive algorithms will be essential to improve the validity and practical applicability of anthropometric assessments.

In sports science, increasing attention is being directed toward multimodal approaches that combine anthropometric measurements with bioelectrical impedance analysis, physiological markers, training-load data, and performance indicators [200]. Such integrated models may provide a more comprehensive understanding of the interactions between body composition, physical performance, recovery, and health status than anthropometric measures alone.

Another important challenge concerns the validation and standardization of emerging body composition indices. Although indices such as ABSI, BRI, CI, and VAI have shown promising associations with metabolic and cardiovascular outcomes, further longitudinal and multicenter investigations are required to establish robust reference values and determine their applicability in diverse populations, including elite athletes, older adults, and clinical populations [199,201].

Finally, the future of anthropometric science is likely to move toward integrated and personalized assessment frameworks that combine anthropometric, physiological, behavioral, and digital health data. The convergence of wearable technologies, artificial intelligence, bioelectrical impedance databases, and advanced analytical tools may enable more precise, individualized, and dynamic monitoring of body composition, health status, and athletic performance across the lifespan [208,209].

Conclusion

Anthropometric assessment remains an essential and practical tool for evaluating body composition, physical performance, nutritional status, and health-related risks. Traditional measurements and advanced indices collectively provide valuable information for athlete profiling, metabolic risk evaluation, and clinical monitoring. However, the limitations of certain indicators, particularly BMI, highlight the need for a multidimensional approach integrating multiple anthropometric parameters with advanced body composition techniques. Future research should focus on improving standardization, developing population-specific

models, and incorporating emerging technologies to enhance the accuracy and applicability of anthropometric evaluation in sports science and health assessment.

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Declaration of competing interest

The authors declare that they have no competing interests.

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