Question: Why SUM

What makes the **s**tandardised **u**ltrasound **m**ethod (**SUM**) more efficient than DXA, ISAK-skinfold-measurements, BIA, A-mode ultrasound (BodyMetrix), or other *indirect* methods.
What are the validity, accuracy and reliability advantages of this *direct* measurement method?

1. A brief answer:

It is primarily the **adipose tissue** (a quantity on the tissue/organ level) that is of concern when optimising the physique of a person - and **SUM** measures the adipose tissue, in particular the subcutaneous adipose tissue (SAT) - which contains the dominating part of the adipose tissue (about 90% in women, and 80% in men). SUM measures the thicknesses of SAT **directly** - with highest **validity** (pulse-echo thickness measurement of a series of representative SAT-layers) - and is the only method with sufficiently high **accuracy** and **reliability** for distinguishing between the SAT-values on the fine scale necessary in groups like athletes of weight-sensitive sports or in anorectic patients, or other groups of lean persons. Further, SUM is the **only available method** that enables detailed **SAT patterning studies** (accuracy: 0.1 mm; reliability: 95%-LOA is 0.2 mm), and determination of the amounts of **fasciae** (fibrous structures) embedded in the SAT. In athletes, the proportion of embedded fasciae typically accounts for 10 to 30% of the SAT.

The **NISOS-BCA (B**ody **C**omposition **A**nalysis**)** software supports the rapid and precise evaluation of ultrasound data as well as the recording of anthropometric parameters to characterize a person's physique.

Portable or wireless **ultrasound systems (B-mode)** are available at competitive prices and are suitable for use in a variety of fieldwork settings.

Except for SUM, **all other methods** in use are **indirect** measurement methods based on various **assumptions** (models) that cause, in many cases, error ranges larger than the values to be measured, particularly in groups of lean persons. When applying various indirect methods in a given person, in a large percentage of cases, measurement differences of several kilograms result. In weight-sensitive sports, almost all male athletes have SAT (and also body fat) values lower than the error ranges of these methods: most elite male athletes of weight-sensitive sports have only 1 to 4 kg subcutaneous adipose tissue, and a similarly low value of body fat. The (relative) measurement errors often exceed 100%, particularly in athletes and other lean individuals; in other words, a person may have double or only half the fat mass erroneously indicated by the measurement. Both skinfolds and A-mode ultrasound fail to differentiate between the skin and the SAT, which, in many athletes, is thicker than their SAT layers. This alone leads to measurement errors exceeding 100%. Moreover, skinfolds measure SAT thickness in an undefined compressed state.

A note on terminology and on validation of measurement methods:

Fat mass (molecular level) and **adipose tissue mass** (tissue/organ level) are different quantities, albeit the dominating portion of fat mass is contained in the **subcutaneous adipose tissue** (**SAT**), particularly in persons with low to medium waist circumferences. The terms **fat mass** and **adipose tissue mass** should be strictly distinguished to avoid confusion. These different quantities (one on the molecular level, the other on the tissue/organ-level) cannot be measured with the same methods. It is unscientific to 'validate' one indirect method with another indirect method (circular reasoning) as both have unknown or only vaguely known error ranges, and the actual errors can be very large when individuals are measured. This can easily be recognised visually when plotting results obtained with different methods applied in the same persons against each other: differences in fat mass or adipose tissue mass up to 100% and above occur frequently. It is often misleadingly claimed that the **indirect method DXA** could be used as a validation method for other indirect methods: DXA was developed for determining bone density. When additionally applied to the commercially lucrative measurement of body fat, this method demonstrates measurement errors of several kilograms, particularly in lean individuals and athletes, and in persons whose body shapes deviate from the 'norm'. This holds particularly true for very tall and/or broad persons and for athletes with their physiques deviating from 'the norm'.

Accuracy demands for biometrical measurement methods: When measuring body mass, we expect the error range to be **far below 1 %**, but surprisingly, when measuring the fat or adipose tissue mass of an individual, error ranges of **100% and above (!)** seem to be widely accepted, although even parts of a kilogram adipose tissue mass make a significant difference for elite athlete. Such data are misleading and cause only confusion. **In our view, it is irresponsible to pass on data containing such substantial inaccuracies to athletes or their support staff.**

We recommend to **participate in a training course on SUM** (www.IASMS.org) to reach the high measurement accuracy and reliability in due course, and to discuss and clear all remaining questions on methodology, applications, study designs, and on physiological importance of adipose tissue.

2. A detailed answer, with scientific references:
Large errors were found when various indirect or doubly indirect methods for measuring adipose tissue were analysed and their outcomes compared [1,2,3,4,5]. Skinfolds measure a double-layer of skin and SAT in undefined compressed state without taking tissue compressibility and skin thicknesses into account: in lean persons like anorexia nervosa patients [6] or athletes [7,8], skin can be thicker than the uncompressed SAT-layer. Clarys [6 4] analysed the '*myths of skinfolds*'. In other studies, comparisons with accurate brightness-mode ultrasound measurements showed large deviations [8,5]. Concerning bio-impedance analyses (BIA), Kerr and Hume stated: [9p.101] "*Interpretation of the data is impeded given the black box approach ...*, and: [9 p.114] *BIA can be considered to be low in accuracy and reliability. Regional body assessment is possible but it is invalid.*" For estimation of body fat lipids ('chemical level'), dual X-ray absorptiometry (DXA) is widely used [10]. Multi-component approaches (4- or 5-component models) are state-of-the-art methods for determining body fat [11], but results are estimations based on model assumptions that include all (non-polar) lipids of the body, not just adipose tissue. Methods like DXA, hydro-densitometry, anthropometry, water displacement methods, BIA, and multi-component models are all indirect methods that should not be used to validate each other (circular reasoning) [12]. When such methods are applied to a single individual, results usually deviate substantially and often surpass the value measured with one of these methods [12]. Beside their inherent methodical shortcomings, sloppily used terminology, too, causes confusion. Clarys, Provyn and colleagues [12,13] suggested to replace the term 'fatness' by 'adiposity' when referring to adipose tissue, and to use the term 'lipids' instead of 'fat' for the ether-extractable constituent – when referring to chemical components. We suggest to base the terminology on the five-level model of body composition of Wang. et al. [14]. This model distinguishes between the following five levels: atomic, molecular, cellular, tissue/organ, and whole body. Recent terminological suggestions [15] are based on these body composition levels. On the molecular level, the term 'fat mass' (FM) includes the (estimated) mass of all fat molecules (non-polar lipids, mainly triglycerides) distributed all over the body, regardless of where they occur. The fat mass is often also expressed as percent of body mass. The counterpart to fat mass is the fat-free mass (FFM), which is the mass of all non-fat molecules in the body. In contrast to the term fat mass, which refers to chemical components of the body, clinicians, sport scientists, athletes, nutritionists, and also the general public are usually interested in the quantities of anatomically defined components with physiological relevance (anatomical level), such as adipose tissue. SUM measures **directly** (pulse-echo-method) the **subcutaneous adipose tissue SAT**, which encompasses the dominating part of total adipose tissue [16].

The adipose tissue (AT is the SAT plus the visceral adipose tissue, VAT) is predominantly fat molecules (about 80 to 85%), with additional contributions from water (about 15%) and protein of about 5% [15]; however, in lean persons, fibrous structures (fasciae) embedded in the SAT, which are mainly built of protein, can amount to about 30% of SAT mass [7,8,5,17,18,19,20]. According to computer tomography (CT) studies of Kvist [16], SAT forms about 90% of AT in women, and 80% in men [16]; however, detailed MRI total body scan studies of various groups of persons (with sufficient resolution) are missing. The ultrasound method SUM directly quantifies the dominating part of adipose tissue, **SAT**, which includes also the dominating part of the body's fat mass (nonpolar lipids, mainly triglycerides). This holds particularly true for persons with low or normal waist circumferences (or waist-to-height-ratios) like athletes or anorectic patients. It should be clear that AT measurements (on the 'anatomical level') **cannot be 'validated'** by fat mass measurements (on the 'molecular level') - **as these are different entities**, albeit with overlap in regard to triglycerides. However, this is obviously not clear to many people in the field - as there are many (pseudo-) scientific studies that attempt to 'validate' the results of measurements at the anatomical level (e.g., skinfolds, ultrasound, other imaging methods, cadaver dissections) with measurements at the molecular level (e.g., DXA, densitometry, BIA, multi-component-models). Astonishingly, it can be observed that such pointless validations are even demanded by reviewers of scientific journals - such incompetency hinders scientific progress.

Some authors suggest (the indirect method) DXA as the 'gold standard' for validation of other techniques, but a review of the literature showed controversial results [13]. In very lean individuals, DXA failed to record any fat in the torso region [21]. The authors interpreted this as impossible results because total fat was 3.3% (95%-CI: 2.2-4.4), abdominal skinfolds 5.8 mm (±0.3 mm), and additionally, there were essential lipids in liver and other organs to be assumed that additionally contribute to torso fat. DXA, uses a series of assumptions because two photon energies cannot distinguish between three quantities: fat mass, bone mineral content, and fat-free mass [10]; these assumptions may result in severe errors in lean persons like athletes or anorectic patients whose physique strongly deviates from the 'reference individual' assumed in DXA-algorithms. Further, DXA depends on subject presentation [1]. Inconsistent results obtained with DXA in groups of athletes have been described repeatedly [22,23], and Clarys, who conducted meticulous validation studies including dissection, bone-ashing, and computed-tomography (CT) stated that *"DXA provides inaccurate and misleading values at all level of its output…"* [12].

On the 'anatomical level', medical imaging methods can be used; however, image segmentation protocols [16] of CT and magnetic resonance imaging (MRI) cause accuracy limitations, and pixel size of MRI total body scans (typically 1.5 mm) is larger than SAT-thicknesses found in lean persons. Further, CT uses ionising radiation and is therefore not applicable for screenings. Brightness-mode ultrasound applied in standardised way (**SUM**) **fulfils the high accuracy and reliability demands** for studies on the fine scale necessary in athletes or in other groups of lean persons [17,18,19,20], and can also be applied advantageously in obese persons [24]. Due to the high quality of the SUM data and the significantly lower costs of ultrasound devices compared to DXA, MRI, or CT, a widespread adoption of this method is expected in various areas where accurate body composition data are of relevance. Normative data [19,20] and training courses [25] are available.

References:

1 Ackland, T.R. et al. Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Med* **42**, 227-249 (2012).
2 WHO Expert Consultation. Appropriate body mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* **363**, 157-163 (2004).
3 Lahav, Y. et al. A novel body circumference-based estimation of percentage fat. *Br J Nutr 119(6), 720-725* (2018).
4 Clarys, J.P., Martin, A.D., Drinkwater, D.T. & Marfell-Jones, M.J. The skinfold: myth and reality. *J Sports Sci* **5**, 3-33 (1987).
5 Müller, W. et al. Body composition in sport: A comparison of a novel ultrasound imaging technique to measure subcutaneous fat tissue compared with skinfold measurement. *Br J Sports Med* **47**, 1028-1035 (2013).
6 Lackner, S; Mörkl, S; Müller, W et al. Novel approaches for the assessment of relative body weight and body fat in diagnosis and treatment of anorexia nervosa: A cross-sectional study. Clin Nutr. 2019; 38(6):2913-2921.
7 Sengeis, M., Müller, W., Störchle, P. & Fürhapter-Rieger, A. Competitive Performance of Kenyan Runners Compared to their Relative Body Weight and Fat. *Int J Sports Med* **42**(4), 323-335 (2021).
8 Sengeis, M., Müller, W., Störchle, P. & Fürhapter-Rieger, A. A. Body weight and subcutaneous fat patterning in elite judokas. *Scand J Med Sci Sports* **29**(11), 1774-1788 (2019).
9 Kerr, A. & Hume,P.A. In Hume, P., Kerr, D. & Ackland, T.R. (edts.): *Best practice protocols for physique assessment in sport*. Chapter 9, p101-116 (Springer, 2018).
10 Pietrobelli, A., Formica, C., Wang, Z. & Heymsfield S.B. Dual-energy X-ray absorptiometry body composition model: review of physical concepts. *Am J Physiol* **271**(6 Pt 1), E941-951 (1996).
11 Heymsfield, S.B. & Waki, M. Body composition in humans: advances in the development of multicompartment chemical models. *Nutr Rev* **49** (4), 97-108 (1991).
12 Clarys, J.P. et al. A macro-quality evaluation of DXA variables using whole dissection, ashing, and computer tomography in pigs. *Obesity (Silver Spring)* **18**(8), 1477-1485 (2010).
13 Provyn, S, Clarys, J.P., Wallace, J., Scafoglieri, A. & Reilly, T. Quality control, accuracy, and prediction capacity of dual energy X-ray absorptiometry variables and data acquisition. *J Physiol Anthropol* **27**, 317-323 (2008).
14 Wang ZM, Pierson RN Jr, Heymsfield SB. The five-level model: a new approach to organise body composition research. Am J Clin Nutr 1992; 56(1):19-28.
15 Tinsley G.M., Heymsfield, S.B. Fundamental Body Composition Principles Provide Context for Fat-Free and Skeletal Muscle Loss With GLP-1 RA Treatments. Journal of the Endocrine Society, 2024, Vol. 8, No. 11.
16 Kvist, H., Chowdhury, B., Grangård, U., Tylén, U. & Sjöström, L. Total and visceral adipose-tissue volumes derived from measurements with computed tomography in adult men and women: predictive equations. *Am J Clin Nutr* **48**(6), 1351-1361 (1988A).
17 Müller, W. et al. Subcutaneous fat patterning in athletes: selection of appropriate sites and standardisation of a novel ultrasound measurement technique. *Br J Sports Med* **50**, 45-54 (2016).
18 Müller, W. et al. 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* **50**(3), 597-614 (2020).
19 Müller W. et al. Accurate Measurement and classification of adipose tissue and underweight. Book Chapter (2025, in preparation)
20 Müller W. et al. Physique of world-class sport climbers. Book Chapter (2025, in preparation)
21 Stewart, A.D. & Hannan, W.J. Prediction of fat and fat free mass in male and female athletes using dual X-ray absorptiometry as the reference method. J Sports Sci 18, 263-274 (2000).
22 Santos, D.A. et al. Accuracy of DXA in estimating body composition changes in elite athletes using a four-compartment model as the reference method. *Nutr Metab (London)* **7**, 22 (2010).
23 Silva, A.M., Minderico, C.S., Teixeira, P.J., Pietrobelli, A. & Sardinha, L.B.. Body fat measurement in adolescent athletes: multicompartment molecular model comparison *Eur J Clin Nutr* **60**(8), 955-964 (2006).
24 Störchle p. et al. Standardized Ultrasound Measurement of Subcutaneous Fat Patterning: High Reliability and Accuracy in Groups Ranging from Lean to Obese. *Ultrasound Medicine Biol* 43(2), 427-438 (2017).
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