Foreword

The study of human body composition is a vivid field of biomedical research. Although more than a century old, this field is dynamic; new branches are emerging due to technological advancements and increased interest in a healthy lifestyle.

Accurate tracking of body composition is essential in the fight against the side effects of obesity and the medical problems associated with eating disorders, underweight and extreme leanness, in the body mass management of people who strive to maintain an optimal build, and in monitoring the constitution of athletes. Thus, body composition testing is important over a wide range of physiques, from the extremely lean to obese.

Monitoring the physique of athletes is of special interest and has gathered momentum recently. In their demanding environment, athletes need guidance to stay healthy and competitive. From a personal perspective, they can only live a complete life by taking care of their minds and bodies. From a societal standpoint, their health is a prerequisite for impressive sport performance. Moreover, athletes are role models for many of us, so their well-being can be regarded as a public health issue. Athletes practicing weight-sensitive sports consider their body fat as a mechanically passive ballast and often disregard the endocrine function of the adipose tissue. Aggressive methods to lose body fat and to reduce body weight excessively are common in many sports. Extreme dieting, dehydration, purging, and excessive training practices may lead to chronic eating disorders and body fat reduction below the essential level. To address this problem, the Medical Commission of the International Olympic Committee formed a Working Group on Body Composition Health and Performance to review the methods in use for quantifying adipose tissue and body fat in athletes.

Over the past century, body composition research encompassed numerous techniques, including cadaver studies to anthropometry, densitometry, isotopic methods, in vivo neutron activation analysis, bioelectrical impedance analysis, dual-energy X-ray absorptiometry, computed tomography, magnetic resonance imaging, ultrasound, skinfolds, and three-dimensional photonic scanning. Some of these techniques, commonly known as field methods, lend themselves to practical applications in clinics, training facilities, and sports event sites, whereas others are laboratory methods that require expensive equipment, adequate space and highly trained personnel. Laboratory methods are often combined to quantify several components of the body. Multicomponent methods quantify body fat (on the molecular level), but they are impractical due to high costs and logistic difficulties; therefore, they are mainly used as criterion measures for the validation of individual techniques.

Most methods developed so far are indirect (e.g. densitometry) or doubly indirect (e.g. bioelectrical impedance analysis). In densitometry, body mass and volume are measured to evaluate body fat content based on the assumption that the density of body fat and that of the fat-free components of the body do not differ from one person to another. In bioelectrical impedance analysis, electric quantities of the body are measured. Population-specific prediction equations are then used to calculate body composition parameters, such as body fat content, the mass of water present in the body, and body cell mass. The Achilles heel of indirect methods is their reliance on assumptions that are tested in most cases against other indirect methods and on samples of the general population, which may differ substantially from the physique of individuals. Multicomponent methods, which are considered to be the current state of the art for body fat measurements (on the chemical level) are not free from these problems, since they employ indirect techniques to assess diverse characteristics of the subject's body (e.g. densitometry to infer body volume), and they are not applicable in the field.

Accuracy and reliability error ranges of methods for measuring the physique of individuals should be an order of magnitude lower than the values to be measured. In individuals with higher percentages of body fat, some of the indirect methods with error ranges of a few percent body fat may fulfil this demand; however, when it comes to measure the physique of lean people who have only a few percent of body fat, substantially lower error ranges are necessary.

This book proposes a different approach to the evaluation of a person's adipose tissue. Instead of indirect methods within reach, it proposes to use high-resolution brightness-mode ultrasound to measure the adipose tissue thickness at selected anatomical locations. Measurement site selection was done by an international panel of experts, whereas the methodology was devised relying on decades of experience in ultrasound. The resulting approach – called the standard ultrasound method, with the acronym SUM – is a direct approach to measure subcutaneous adipose tissue. Most importantly, it also allows for an accurate measurement of the skin thickness and of the thickness of the fat-free fibrous connective tissue (embedded fasciae). The connective tissue serves as a scaffold for the fat lobules (groups of adipocytes – fat cells); it contains capillary vessels, nerve endings, as well as collagen and elastin fibres that confer mechanical resistance to the subcutaneous adipose tissue. The adipocytes store fat in the form of triglycerides in their cytoplasmic lipid droplets.

Besides an engaging presentation of the SUM, this book also contains a carefully developed improvement of the body mass index (BMI), termed mass index (MI), which adjusts body mass not only for height but also for the individual's body shape. This meets a condition formulated by Quetelet in his anthropometric work of 1842, which served as the basis for the BMI (also known as Quetelet's Index). For the MI definition, the Cormic index (the ratio of sitting height to stature) is used for taking into account the different body shapes of persons of the same stature, but with different leg and upper body lengths. It is pointed out that neither BMI nor MI can differentiate between fat and muscle mass; in other words, they are designed to assess body mass with respect to body dimensions, but not body composition. The MI is equal to the body mass times the reference value divided by both stature and sitting height and has the same unit as the BMI (kgm^{-2}). For deriving the reference values in the MI formula, which distinguishes between men and women, the Cormic index medians of large groups of both persons with high and low physical activity were used. For a person with a Cormic index close to the reference value, MI and BMI are equal, and for a person with long legs and a short upper body, the MI is higher than the BMI, and vice versa. The widely used World Health Organisation (WHO) criteria for classifying normal weight and underweight can remain when applying the MI instead of the BMI, with the advantage that the MI also reflects the pronounced effect of body proportions and, therefore, has a greater diagnostic value. From a practical standpoint, it is important that the MI is almost as easy to determine as the BMI.

The data sets from over 2,000 participants presented in this book reveal that, across all corresponding groups of adults, women typically exhibited BMI and MI values about 2 kgm^{-2} lower than men, despite the substantially higher adipose tissue levels observed in women. Based on this compelling evidence, the authors suggest a reconsideration of the current WHO classification, which does not distinguish between sexes.

BMI, designed to assess weight in relation to height, lacks the validity to distinguish between levels of obesity or leanness in individuals. Such misclassification of an individual's body composition may lead to unhealthy behaviour. Similarly, particularly in lean persons, other indirect measurement approaches also soon reach their limits. Because of insufficient accuracy, W. Müller discarded body composition data from over 100 athletes collected during the 2002 Winter Olympic Games and started to develop the highly accurate and reliable brightness-mode ultrasound method for measuring adipose tissue, and in parallel developed the MI, following a demand not only addressed by Quetelet, but also by the results of comprehensive epidemiological studies and by the WHO Expert Committee on Physical Status. These methodological improvements have been continuously refined since then and are presented in finalised form in this book. Both variables are essential for determining grades of leanness and underweight and for performance optimisation in sports.

How is this book structured? First, the need for accurate body composition assessment in athletic populations and other groups of lean individuals, as well as the need for the SUM, is argued in an evidence-based manner. Then, the capabilities of the SUM are illustrated in an original study conducted on world-class climbers – the first of its kind, including 97% of the climbers who reached the semi-finals of the IFSC Climbing World Cup in Innsbruck, Austria, 2022 (International Federation of Sport Climbing, IFSC).

Once the reader's curiosity has been aroused by the results concerning climbers' physiques, the SUM is described in detail. A remarkable feature of it is the gentle learning curve. Training is important, but it can be completed within hours. The positions of the standard measurement sites are expressed relative to external reference points, in terms of the subject's height, so they can be located without a deep knowledge of human anatomy. The acquired ultrasound images can be evaluated semi-automatically, using a dedicated software that measures, on its own, thicknesses at hundreds of locations situated symmetrically around the target site. Moreover, the software includes nonlinear calibration functions to provide estimates of the total volume and mass of subcutaneous adipose tissue. In most athletes and in lean people whose waist circumference to height ratio is low, most of the adipose tissue is subcutaneous; thus, in such cases, the subcutaneous adipose tissue measured by SUM provides an excellent measure of the total adipose tissue mass. The accuracy of individual thickness measurements by ultrasound is in the range of 0.1-0.2 mm, depending on the ultrasound frequency; the latter is chosen to ensure a desired ultrasound penetration depth (the lower the frequency, the deeper the penetration but poorer the image resolution). For the sum of thicknesses measured at eight sites, the reliability was found to be 1.1 mm in lean people and 1.5 mm in non-obese people of average build. The corresponding reliability of subcutaneous adipose tissue mass estimation is below 0.15 kg in lean subjects and below 0.2 kg in average subjects. In this respect, SUM outperforms all other methods of body composition assessment. Such a high accuracy is necessary when levels of leanness are to be determined in anorectic persons or in athletes of weight sensitive sports. This will become clear to the reader when they study the results of elite sport climbers, a typical weight-sensitive sport, presented in this book. Yet, also in scientific studies investigating the impact of adipose tissue or fat mass on physiological and pathophysiological variables, given correlations can be masked by too low accuracy and reliability of the methods used.

Besides providing an up-to-date, detailed overview of the literature, the authors also report original research findings. Among them, special attention should be paid to SUM data of 1072 physically active persons, including top-class athletes of diverse sports, and 1006 untrained subjects from the general population. Based on statistical analysis, reference values are proposed for the sum of subcutaneous adipose tissue thicknesses measured at the eight standard sites of ultrasound measurements. These represent a solid foundation for future research.

In conclusion, this book is a thorough and rich source of information, which might well become the ultimate guide for anyone interested in an accurate assessment of the subcutaneous adipose tissue. It is likely to elicit the interest of a broad readership, including trainers, athletes, experts affiliated with sports federations, sports medicine physicians, and clinicians of diverse specialties in which nutritional status plays an important role.

— Adrian Neagu (July 2025)