A requiem for BMI in the clinical setting

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Purpose of review
Quetelet reported in the nineteenth century that body weight varies across adults with the square of height. Quetelet's index, now known as BMI, is accepted by most health organizations as a first-level measure of body fat and as a screening tool for diagnosing excess adiposity. Modern imaging methods now, however, indicate that BMI has limited predictive value for estimating body fat and lean mass at the individual level. The use of BMI as a measure of body composition in the clinical setting should therefore be challenged.

Recent findings
Recent studies enrolling cancer and surgical patients reported discrepant outcomes when BMI was used as a body composition surrogate. Sarcopenia, loss of muscle mass and function, which affects the elderly and those with chronic and acute diseases, is not accurately diagnosed with BMI. The distribution of adipose tissue is not characterized by BMI, specific measures of which have greater predictive value for metabolic impairments and clinical outcomes.

Summary
BMI, as the traditional tool for assessing malnutrition and obesity, is not appropriate to accurately differentiate between important body weight components and therefore should not be used for making clinically important decisions at the individual patient level.

Keywords
BMI, body composition, malnutrition, obesity, sarcopenia

INTRODUCTION

L.O.V.E, a 19-year-old Olympic gymnast, is admitted to the emergency department with acute appendicitis. She undergoes a laparoscopic appendectomy but on the subsequent 2 days presents several vomiting episodes and abdominal distension. She undergoes nutritional screening, as demanded by the hospital quality protocol, using the malnutrition universal screening tool (MUST). She is classified at a high risk of malnutrition based on her current BMI of 17.7 kg/m^2, although she has had no loss of body weight and her current disease has not yet impacted the 'acute disease effect score'. Despite the latter, but due to her lean body composition, which placed her at risk according to the used screening tool and her vomiting, she is prescribed parenteral nutrition. As a consequence of subclavian vein access, she develops a 30% right pneumothorax, which is then drained.

S.E.E., a 79-year-old man with perforated diverticulitis and peritonitis, is admitted to the ICU after a right colectomy and a colostomy. He develops severe abdominal distension with vomiting on the subsequent 3 days. As a routine protocol, he undergoes nutritional screening, using the same above instrument (MUST). He is classified at a low risk of malnutrition because his current BMI is 32.2 kg/m^2, he has not lost weight and has not been eating only in the last 4 days. Therefore, he should have reassessment within a week based on his screening score. However, the professional who undertakes the screening is well trained and decides to carry out a full nutritional assessment that further indicates this patient to be severely malnourished.

The two above clinical cases are examples of how tools that rely on BMI [1] might mislead to

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KEY POINTS

- BMI has a good correlation with % body fat at the population level, but the predictive value at the individual level is very limited.
- BMI use in clinical practice may jeopardize the nutritional diagnosis, in particular of malnutrition.
- BMI less than 30 kg/m^2 does not exclude the presence of metabolic risks associated with the excess of adiposity.
- BMI at least 30 kg/m^2 does not exclude the presence of low muscle mass (sarcopenic obesity), mainly in some clinical situations as in elderly, cancer, chronic diseases and critically ill patients.

equivocal situations that place patients at increased risks, although they do not consider this variable alone. L.O.V.E. was prescribed unnecessary parenteral nutrition, while S.E.E., if not further nutritionally assessed, would have been treated later than recommended. It is indisputable that BMI has been valuable ever since its development. However, in current clinical practice, particularly when the obesity pandemic is mounting worldwide [2], relying on BMI alone or tools to screen or assess the nutritional status of individuals may be misleading and does not help the diagnosis of a hidden burden in the hospital setting [3,4]. Furthermore, as an instrument of body composition assessment, BMI lacks the capacity to provide adequate individual diagnoses because of its nonspecific characteristics, which will be discussed in detail in the next sections.

BACKGROUND

BMI resulted from the initial studies carried out during the mid-nineteenth century by Lambert Adolphe Jacques Quetelet, the renowned Belgian astronomer, mathematician and sociologist. He reported that body weight (W) across adults varied with the square of height (Ht). This observation, repeated later by others [5▪], is recognized as Quetelet's rule: W α Ht^2. According to Quetelet's Rule, W/Ht^2 is a shape index that is independent of height. Later, workers in the early twentieth century named the shape index, W/Ht^2, Quetelet's Index. Several such indices were developed during this time period as a means of describing individual and group health and nutritional status.

More than one century following Quetelet's seminal observation, Keys *et al.* [6] at the University of Minnesota reported that the shape index W/Ht^2 showed the highest correlation with adiposity among the factors evaluated, measured as the sum of skinfolds and %fat by underwater weighing. The authors renamed Quetelet's index as BMI, and this taxonomy remains in place today.

BMI today is taken by most major health organizations as the first-level measure of adiposity. As a screening tool, BMI is relatively easy to calculate from measured or self-reported weight and height. Cost is low and there are no individual health risks posed by measuring weight and height. BMI weight guidelines are simple and clear.

At the population level, BMI is highly correlated with %fat. As an example, Fig. 1 presents a scatter plot of BMI against %fat for men (left) and women (right) who participated in the National Health and

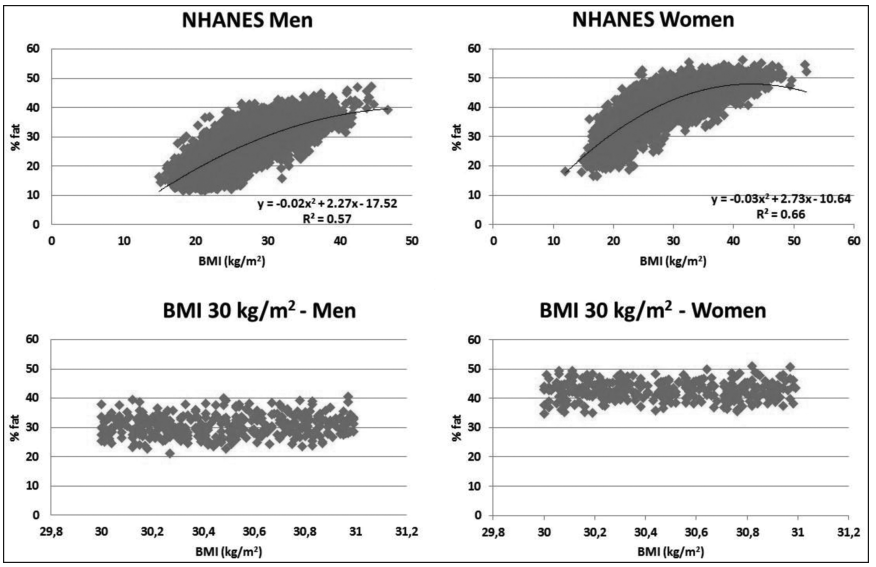

FIGURE 1. %fat varies from 21.2 to 40.5% for men (lower left) and from 34.7 to 50.9% for women (lower right). This observation shows that BMI has a limited predictive value at the individual level.

Nutrition Examination Survey (NHANES 1999–2004) [5▪]. Body fat was measured by dual-energy X-ray absorptiometry (DXA). In this example, the correlation between BMI and %fat has an R^2 of 0.57 for men and 0.66 for women, both $P < 0.001$. Note that the relation between BMI and %fat is curvilinear and that this function can be linearized by using inverse BMI (1/BMI) as the predictor variable for %fat.

Despite the good correlation between BMI and %fat at the population level, variability is large at any given BMI level. For example, at BMI 30 kg/m^2 for the NHANES individuals plotted in Fig. 1, %fat varies from 21.2 to 40.5% for men (lower left panel) and from 34.7 to 50.9% for women (lower right panel). This observation shows that BMI has a limited predictive value at the individual level.

What factors account for this variability? First, %fat at any given BMI level is greater in old people than it is in young people [5▪]. This observation reflects the loss of skeletal muscle and other lean tissues that are typical in most adults with ageing. Second, the NHANES data set includes three main ethnic groups, non-Hispanic white, non-Hispanic black and Mexican American. For the same BMI and age, predicted %fat is smaller for non-Hispanic black individuals and larger for Mexican American individuals than it is for non-Hispanic white individuals [5▪]. These variations, reported for other race/ethnic groups, reflect differences in body shape and composition. A third factor influencing BMI–adiposity relations is physical activity levels. High levels of exercise, particularly weight training, increase skeletal muscle mass and through that mechanism (after controlling for body weight) reduce body fat. Thus, active exercisers have a lower %fat for the same BMI than sedentary adults. After controlling for these three BMI-adiposity effects, other likely factors include smoking, genetics and other mechanisms.

BMI AND MALNUTRITION

BMI is frequently used by various investigators and societies to determine the nutritional status and prognosis of patients, particularly in the cancer and surgical populations [7–20]. A recent study carried out in German geriatric trauma centres showed that 50% of the institutions relied on BMI to diagnose malnutrition [21]. Thus, one could argue that if there are data pointing to such nutritional predictive capacity of BMI, why should we be speculative about its role in the clinical setting?

Chris Anderson [22] has raised attention to an important aspect we should address when analysing data: ‘‘Scientists are trained to recognize that correlation is not causation, that no conclusions should be drawn simply on the basis of correlation between X and Y (it could just be a coincidence). Instead, you must understand the underlying mechanisms that connect the two. Once you have a model, you can connect the data sets with confidence. Data without a model is just noise.’ Furthermore, in the modern era of petabytes, computers and statistics have made data interpretation easier but not necessarily more clinically fit, especially for individuals such as those presented herein, and caution should be the tone when interpreting them. In these regards, health data without clinical reasoning may jeopardize patients’ outcomes and treatments.

The Adjuvant Colon Cancer End Points database analysis of 25 291 patients showed that men with stage II or III disease who were either underweight or obese had overall survival, disease-free survival and time to recurrence results worse than those with an intermediate BMI and when compared with women with low BMI [23]. Renfro *et al.* [18] showed that low and high BMI (a U-curve shape) was associated with an increased risk of progression and death among colon cancer patients. Further, men with low BMI presented with poorer survival than women. With respect to these data, they may indicate that men with low BMI lost more weight than women and thus had a poorer nutritional status.

Another study encompassing surgical colorectal cancer patients and using multivariate analysis indicated that low BMI and stage III and IV disease were identified as independent prognostic factors for decreased survival. In addition, patients with low BMI presented with more severe postoperative complications and poorer prognoses. On the contrary, a higher risk of mild postoperative complications was seen in the high-BMI patients who paradoxically exhibited ‘superior’ survival outcomes compared with the normal-BMI patients. The authors attribute the findings to the ‘obesity paradox’ [10]. In this case, an interplay between advanced disease and loss of muscle mass as well as adiposity may explain the results, which have been well demonstrated to occur in cachexia syndrome. In the latter condition, a significant depletion of muscle mass is related to the inflammatory status trigerred by the tumor, as well as, the production of tumor-related factors such as the proteolysis-inducing factor [24].

Among 106 resected pancreatic cancer individuals, length of hospital stay was associated with low BMI and serum albumin. In addition, low concentrations of albumin, node positivity and poor differentiation were associated with worse overall survival on multivariate analysis [25]. Pancreatic cancer patients are usually severely malnourished

at the time of diagnosis [26], with only 20% of them presenting resectable disease. This might explain why the results from Gavriilidou *et al.* [25] indicated that node positivity and poor tumour differentiation together with low albumin (all of them potentially associated with the aggressivity of the tumour) negatively impacted outcome variables.

On the contrary, Allard *et al.* [27], in a recent Canadian cohort study of hospitalized patients, did not show any association between low BMI and length of hospital stay, while those patients diagnosed as malnourished by subjective global assessment (SGA) or with low hand grip strength had an increased hospitalization time, after controlling for demographic, socioeconomic and disease-related factors and treatment.

In breast cancer patients at the beginning of chemotherapy, only 3.2% of the women were classified as being low weight according to BMI, but when assessed by SGA, 19.2% of them were malnourished [28]. Among Swedish elders, the prevalence of undernutrition in men and women was 3.9 and 8.6%, respectively, when assessed by knee height and demispan equations, compared with 2.4 and 5.4% by standard BMI. There was a more pronounced discrepancy for all women aged 85+ years (16.5 vs. 10% by standard BMI). The authors attribute their results to the inaccurate height estimation among the elderly [25].

In summary, the diagnosis of malnutrition, a highly prevalent syndrome that negatively impacts patients' morbidity, mortality, length of hospital stay and costs [29,30], may be jeopardized if BMI is used alone as previously discussed.

BMI LESS THAN 30 kg/m^2: CAN WE IDENTIFY HARDY LOOKING AT LAUREL?

BMI is the main tool used to define obesity, although its limitation is well known [31]. On the basis of BMI, we have seen the dramatic increase of global obesity prevalence, from 105 million in 1975 to 641 million in 2014. If overweight is included, approximately 40% of the world's population and two out three Americans have BMI more than 25 kg/m^2 [32▪▪].

The data from NHANES 2005–2012 showed that 30% of individuals with normal BMI were cardiometabolically unhealthy and more than 74 million individuals would have a misclassification of their cardiometabolic health according to BMI categories [33▪]. These findings prove that the use of BMI as the general indicator of obesity (excessive fatness) is not suitable to diagnose, prevent and treat obesity-related conditions in clinical practice [34].

Table 1. Techniques of body composition according to ability to assess body fat distribution, precision and accuracy and availability in clinical practice

Body composition technique	Assessment of body fat distribution	Accuracy and precision	Use in clinical practice
Weight and BMI	No	+	++++
Circumferences (waist and hip)	Yes	+	++++
Skinfold thicknesses	Yes	++	++++
Bioelectrical impedance analysis	No	++	+++
Dual energy X-ray absorptiometry	No	+++	++
Computerized tomography	Yes	++++	++
MRI	Yes	++++	+

Adapted with permission from [35▪▪].

Although BMI is the most used tool to assess the excess of adiposity, not only is the amount of fat a determinant of risk associated with obesity but also fat distribution, the central or android distribution being associated with a higher risk than the peripheral or gynoid distribution. This abnormal fat distribution may be the reason explaining the higher metabolic risk found in individuals with normal weight [35▪▪]. The use of other measurements, such as waist circumference (WC), skin fold thickness, waist-to-hip ratio and waist-to-height ratio, can help to identify this anomalous distribution in clinical practice. Table 1 summarizes body composition techniques that can be used alone or in combination with BMI to increase its ability to identify body fatness.

BMI shows no good agreement in the assessment of obesity when compared with these methods. In a sample of cancer patients, it was shown that when obesity was defined by excess of fat mass using bioelectrical impedance analysis, BMI had 56% false-negative results in individuals classified as nonobese (BMI < 30) but with a high fat mass index [36]. Kjær *et al.* [37] showed that there was only a fair agreement between WC and BMI in the assessment of obesity in a national sample of Norwegians. In a cohort of patients undergoing coronary artery bypass grafting, patients in the upper WC quartile in each BMI category showed an increased risk of adverse effects after cardiac surgery when compared with the lower three WC quartiles, indicating that the risk associated with a higher adiposity can be found at any BMI [38].

Body composition techniques have shown that metabolic impairments can be found in any BMI

Table 2. Obesity classification, based in body mass index, body fat amount and distribution, risk for diseases and metabolic impairments

	Body fat	Risk for cardiometabolic disease	Metabolic impairments
Normal-weight obesity (NWO) BMI 18.5–24.9 kg/m^2	↑ ↑ body fat ↑ ↑ VAT/SAT ratio	Increased	Absent
Metabolically obese normal weight (MONW) or thin outside fat inside (TOFI) BMI 18.5–24.9 kg/m^2	↑ ↑ body fat ↑ ↑ VAT/SAT ratio	Increased	Present
Metabolically healthy obese (MHO) BMI ≥ 30 kg/m^2	↑ ↑ body fat Normal distribution	Absent	Absent
Metabolically unhealthy obese (MUO) BMI ≥ 30 kg/m^2	↑ ↑ body fat ↑ ↑ VAT/SAT ratio	Increased	Present

VAT/SAT, visceral adipose tissue/subcutaneous adipose tissue.
Adapted with permission from [35▪▪,39▪▪].

category. On the basis of the presence of metabolic impairments and the amount and distribution of body fat and BMI, there are four different phenotypes to define obese individuals (Table 2). It can be seen that two of them have normal weight (BMI 18.5–24.9 kg/m^2), and the difference between normal-weight obesity (NOW) and metabolic obese normal weight (MONW) is the metabolic impairment present in the last one, probably caused by the excessive visceral fat. Because of this special characteristic, the MONW is called 'thin on the outside fat on the inside' (TOFI). The metabolic healthy obese (MHO) is a new concept based on the findings that 15–45% of obese individuals show no signs of metabolic impairment, despite having a higher body fat mass [35▪▪,39▪▪].

In conclusion, a BMI less than 30 kg/m^2 does not exclude the metabolic risks associated with an excess of adiposity. At any BMI, even with normal weight, an unhealthy metabolic profile may be present, and BMI alone is not enough for its identification. Other techniques of body composition assessment should be implemented in our clinical practice to better identify them.

BMI AT LEAST 30 kg/m^2: CAN WE SEE LAUREL INSIDE HARDY?

There are several clinical situations in which skeletal muscle loss can occur in obese individuals, and simultaneously, there could be adipose tissue accretion, generating the condition known as 'sarcopenic obesity' or 'sarcobesity' [31,40▪▪]. Sarcopenic obesity can also be called the 'hidden' sarcopenia because the underlying muscle loss is generally undetected when assessed by BMI alone. This condition is found not only as a consequence of age-related changes in body composition but also in situations in which the combination of inactivity, inflammation and anorexia can determine the increase of fat mass and loss of skeletal muscle and dysfunction as in chronic diseases [41].

Sarcopenic obesity in ageing

As a reflection of the obesity pandemic, the prevalence of geriatric obesity is also increasing, and more than one-third of U.S. adults older than 60 years have a BMI at least 30 kg/m^2, reaching 40.8% in the range of 65–74 years [42]. The combination of inactivity, the ageing process and nutritional impairments leads to a higher risk of development of sarcopenic obesity in the elderly. This age-related muscle mass loss can be further exacerbated with weight reduction therapies alone [43]. Another risky situation is the obese old patient admitted at the hospital. The combination of bed rest, inadequate protein ingestion and a catabolic state can lead to a loss of almost 95 g/day of muscle mass [44]. In none of these situations can BMI identify the presence of sarcopenic obesity. The importance of its early diagnosis is that, as in other clinical situations, sarcopenic obesity seems to result in a synergistic negative effect in functional impairment [43]. For this reason, it is very important to perform sarcopenia screening and diagnosis in these older obese patients using the recommended criteria alongside BMI assessment [41] to prevent the development of sarcopenic obesity and promote early interventions.

Apart from the elderly obese, a large proportion of obese patients can be affected by several clinical conditions associated with the development of sarcopenia, such as those with cancer, in the ICU or with chronic diseases.

Sarcopenic obesity in cancer

During cancer investigation/treatment and its progression, abdominal computed tomography (CT) scans can be conveniently used to assess body composition as an opportunistic tool, and this approach has shown that obesity (BMI $\geq 30\,kg/m^2$) is frequently associated with skeletal muscle depletion and that BMI leads to a misclassification of these patients [45].

Although several tools can be used to assess sarcopenia (defined only as low muscle mass), there is no consensus about the definition of obesity itself (Table 3). For this reason, the prevalence of sarcopenic obesity can vary if based on BMI only (15–36% in patients with BMI $> 25\,kg/m^2$) or on excess of body fat assessed by other body composition tools (1–29%) [46▪▪]. CT is an opportunistic body composition tool in cancer patients, as muscle mass and adipose tissue and its distribution can be easily estimated from a scan at the third lumbar vertebra [47▪▪].

Sarcopenic obesity in cancer is associated with a decrease in functionality and negative clinical outcomes, such as higher mortality, dose-limiting toxicity associated with chemotherapy, worse postoperative outcomes and longer hospitalization [36,46▪▪,48▪▪]. Lou *et al.* [49] showed that the presence of sarcopenia, defined as low muscle mass, low strength and low performance, can increase six times the risk of postoperative complications in gastric cancer patients.

Kazemi-Bajestani *et al.* [50▪▪] reviewed studies that used CT to assess muscle and fat mass in cancer patients and tried to explain their relationship with negative outcomes (chemotherapy toxicity, postsurgery complications and survival). The studies reviewed showed that muscle depletion was seen in patients with any BMI. The adverse outcomes were significantly related to muscle depletion, and sarcopenic obesity had a strong association with poor survival. This review indicated the superiority of CT for the assessment of muscle mass and fat in cancer patients, instead of only weight and BMI.

Table 3. Methods used in the assessment of obesity and sarcopenia for sarcopenic obesity diagnosis

	Method	Assessment
Obesity (excess of body fat)	Anthropometry	BMI
	Abdominal CT scan	% body fat or visceral fat area
	DXA or BIA	Fat mass index
Sarcopenia (low muscle mass)	Abdominal CT scan	Skeletal muscle index
	DXA	Appendicular skeletal muscle index
	BIA	Fat-free mass index

BIA, Bioelectrical impedance analysis; CT, computerized tomography; DXA, dual-energy X-ray absorptiometry.
Adapted with permission from [46▪▪].

Sarcopenic obesity in ICU and chronic diseases

One-third of critically ill patients are obese [51▪], and these patients undergo all of the other determinants of skeletal muscle loss: systemic inflammation, hypermetabolism and catabolism, inactivity and insufficient protein intake. Segaran *et al.* [52] showed that a high BMI did not prevent muscle loss in the ICU, and muscle loss was approximately 1.6% per day. The combination of a high prevalence of obesity and muscle loss can be the cause for the development of sarcopenic obesity in these patients, and again, the high BMI would mask its identification. Although the negative effects of sarcopenic obesity are not well known in ICU patients, obese patients should have a complete nutritional assessment and sarcopenia screening as any other patient, and they should receive special attention regarding an adequate amount of protein and energy intake.

Sarcopenic obesity in the ICU can be even more hidden if the patient is older. Ageing is the primary determinant factor for the development of sarcopenia, and patients 65 years and older were responsible for more than half of the occupancy of ICU days in the United States in 2000 [53]. Sarcopenic obesity in the elderly can be found at any BMI because of the simultaneous changes in fat and muscle during the ageing process. Therefore, this condition should be considered independently of BMI, so that preventive measures, such as early mobility and protein supplements, can be delivered to avoid the appearance of sarcopenia-related disability.

Body composition tools are not routinely available for the ICU population, and BMI does not give all the information to identify sarcopenic obesity and its relationship with outcomes. Simple measurements, such as mid-arm muscle circumference, assessment of fat loss and muscle wasting by using the SGA seem to be better predictors of mortality than BMI alone [54,55▪]. Ultrasound and abdominal CT scans acquired during routine care are new emerging tools for body composition assessment in ICU patients, but further validation of these techniques in this population is still needed.

Sarcopenic obesity is also prevalent in other chronic diseases besides cancer and ICU patients. Joppa *et al.* [56▪] showed that the prevalence of sarcopenic obesity is 2.5 times higher in chronic

obstructive pulmonary disease patients than in controls (10 vs. 4%, respectively), and sarcopenic obesity has a negative impact on physical performance. It is noteworthy that the mean BMI for sarcopenic obese men and women was 27.9 and 23.7 kg/m^2, respectively, giving no clue about body composition abnormalities. In patients with cirrhosis assessed by CT, sarcopenic obesity was present in 20% of the sample, and it was independently associated with a worse survival [57▪]. The mean BMI of sarcopenic obese patients was 30 ± 0.5 kg/m^2, not significantly different from patients with no muscular abnormalities, showing again the uselessness of BMI in this situation.

CONCLUSION

BMI, a traditional tool used for the screening and assessment of malnutrition, obesity and healthy body composition among populations, is not appropriate to differentiate between components of body weight, and it does not appear to be a reliable marker of adiposity at the individual level. Simple questions about weight loss, inadequate food intake or loss of appetite, independently of a BMI value, is a better means of screening for and/or assessing malnutrition. The use of new body composition tools may help identify metabolic risk by assessing body fat and its distribution as well as the loss of muscle mass associated with malnutrition and sarcopenia.

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Conflicts of interest

There are no conflicts of interest.

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- ▪ of special interest
- ▪▪ of outstanding interest

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