 doi:10.20944/preprints202008.0211.v1

Grip Strength Generalization of the Body Mass Index

Alexandru Godescu
Applied mathematics, computer science
Alexandru.godescu@yahoo.com

Abstract

The Body Mass Index (BMI) formula has been developed by Belgian mathematician Adolphe Quetelet and published in 1840 [1] as a law of nature and society, based on statistics about the weight and height of the population of that time, the first part of the 19th century. He called it "social physics". From then, for nearly two centuries, the BMI had been the most important formula describing the normal relations and ratio of weight to the square of the height for humans. The problem arises if the BMI formula, developed in the first part of the 19th century is still good today when the type of work people perform is very different? In modern times, most people are less muscular than at the time when the BMI was developed because they do not work physically as heavy as at that time. In many cases, the Body Mass index can predict mortality, morbidity and illness but not always, for example cases such as (a) the obesity paradox for some cardiovascular problems and (b) the U shape mortality paradox as well as (c) false positive obesity diagnostic in regard to people who are strong and muscular, have low body fat percentage but are classified as obese by the BMI and (d) cases where BMI is normal but people have an "obese metabolism" (e) BMI normal but high fat percentage. The objective is to develop a formula good for all body types, a formula that makes the difference between fat and non-fat body weight such as muscle and body frame and quantifies the effect of strength and fitness, which BMI does not. Another objective is to develop a formula to predict the health risks and fitness status of people, better than BMI. The first generalizations of BMI using anthropometric metrics could be found in [2], where I discuss and analyze many formulae, developed, tested, and simulated by me, using similar new methods, accounting for body shape, physical shape and body function, making the difference between muscle mass and fat, fat and non fat body weight. Nearly all formulae and methods developed and proposed in this new model are new, never published before. Many experiments published before, in highly cited papers show that grip strength and muscle strength is a predictor of health, mortality, morbidity, endocrine and metabolic disease outside the BMI and anthropometric measures. The purpose of my formula is to explain the outcome of those experiments and create a formula which predicts these experiments [21][23][24][25][26][27][28][29][30][31][32][33][34][35] [37][38][39] [40][41][16][17][18][19][20][22][36]

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

1. Introduction

The classic body mass index (BMI) observed as a law of nature and society in the 19th century by Adolphe Quetelet [1] is a good formula for active hard working people as those who were the basis of the statistic made by Adolphe Quetelet in the first part of the 19th century. Today much of the population is less active and works fewer hours and not so heavy as at that time. This means it is possible to make the case that BMI overestimates the maximum normal weight a modern person can have.

The standard BMI formula of Ancel Keys [5] and Adolphe Quetelet [1] is

$$\mathrm{BMI} = \frac{\mathrm{weight}}{\mathrm{height}^{2.0}}$$

It is possible to define it as a function

$$\mathrm{BMI}(\mathrm{weight},\mathrm{height}) = \frac{\mathrm{weight}}{\mathrm{height}^{2.0}}$$

This difference is apparently small but it may have significant mathematical implications. First I introduced this notation in [2].

2. The obesity pandemic and its health and economic consequences

Obesity is a major health problem in our times and one of the most important preventable causes of premature death, mortality, morbidity, loss of function and ill health [6]. A larger introduction and description of the methods could be found in my "Anthropometric generalization of BMI" [2]. BMI is perhaps the most common way obesity is diagnosed and quantified by the public and by doctors and researchers.

3. Limitations of the BMI

In many cases, the Body Mass index can predict mortality, morbidity and illness but not always, for example cases such as (a) the obesity paradox for some cardiovascular problems and (b) the U shape mortality paradox as well as (c) false positive predictions in regard to people who are strong and muscular, have low body fat percentage but are classified as obese by the BMI and (d) cases where BMI is normal but people have an obese metabolism (e) BMI normal but high fat percentage.

The standard BMI formula or function makes no distinction between muscles and fat, or between various body types and studies have cast doubt on its validity in these circumstances. [3] No existing method, not even those using complex laboratory methods, are able to capture the quality of the muscles, their functionality, and their neural command structures which is relevant for health but is different from their mass. The BMI was never defined as a function before, but this definition opens new analytical possibilities, this change of perspective can create new sport science and new health science. It is convenient for mathematicians and computer programmers to

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

think and model the problem in this way. The BMI does not take in account the body fat distribution. The abdominal body fat is a risk in metabolic and heart disease [45]. Of course BMI does not account for the distribution of fat so it is not a predictor of the consequences of abdominal fat.

The BMI does not take in account the level of muscular development and strength but muscular development is a predictor of health and it is associated with better health and lower mortality and morbidity risk. [16][17][18][19]
The BMI does not take in account the change of the demographic base. The BMI is based on the statistic made in the first part of the 19th century [1], but those people had different occupations and body types and body composition, compared to the people who live today. Most people are different today in terms of body composition, nutrition and occupation than the population was at that time when the BMI (body mass index) was developed, because most people now do not have heavy physical work occupations as in the 19th century and are less muscular now and have occupations where they do not develop their body, physical strength and endurance in a comparable way to the people who lived in the first part of the 19th century. Is the same formula used for lean and strong people in the 19th century still correct during our times? They were shorter, stronger, leaner and had usually a smaller life expectancy. Despite the fact that most people have professions where they do not develop their physical strength now, there are people who developed their body through sport and exercise more than it was possible in the first part of the 19th century, the most muscular people of our time have more muscles than people living at that time in the 19th century. The U shape mortality paradox [46] shows BMI has limitations in predicting death in older people. Therefore we must find a better formula because BMI theory fails to explain some statistics and experiments. The obesity paradox [47] has been documented in patients with heart failure. The low BMI and obesity metabolism paradox is also a problem not solved by the BMI. BMI is an indicator of obesity, it does not differentiate between adiposity types. [48] Metabolic syndrome is in particular associated with abdominal obesity [49] which the BMI does not capture. [10] shows waist circumference is a predictor of mortality independent of the BMI. [11] found that both waist circumference and in combination with the BMI is a predictor of mortality. This causality had been included in my formulae in "The anthropometric generalization of BMI" [2] and is included also in the formulae in this paper. Waist circumference had been associated with mortality independent of BMI, at the same BMI, higher waist circumference meant higher death risks. [12] This is not part of BMI prediction power and for this reason my formulae of "The anthropometric generalization of BMI" [2] which combines the two indicators have more prediction power than BMI alone. Waist circumference and waist to height ratio are independent of BMI a factor in predicting death. [13] The ratio of waist to chest is inversely correlated to lung function even in children [14]. This is an important result because a large number of health problems derive from this including death from respiratory infections and predicts why obese people were much more likely to die from COVID 19. I implemented this causality in [2] in the anthropometric generalization of the body mass index. Clearly, this is not predicted through the BMI alone. [15] shows the waist to chest ratio correlates with

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

visual attractiveness of males suggesting there is a correlation with evolutionary fitness.

4. Experimental proof of the grip strength as a predictor of health

The body fitness is a predictor of mortality independent of BMI and central abdominal obesity, and this means using strength and fitness as a factor in a new formula would have a better prediction power than that of BMI [9]. Mid arm strength is found in [16] to be a better predictor of death in patients with COPD. This is why the new formulae developed bellow uses grip strength to generalize the BMI and represents a formula with a better prediction and diagnosis power than the BMI. Relative muscle mass is inversely related to insulin resistance is found in [17] and this is certainly a property not predictable from BMI, it is beyond BMI. The muscle mass is inversely related to cardiovascular mortality [18], something not captured by the BMI or other metric which does not consider muscle mass and strength. [19] found muscle strength is a strong predictor of mortality, it is clear this is not captured by BMI or by other metrics such as that described in [4]. [20] found an association between muscle strength and mortality in men, yet the previous formulae such BMI or Broca index or [4] cannot capture this association because they do not quantify muscle mass or strength. [21] shows that hand grip strength, correlates with overall strength and is a predictor of death in older people. Classical body weight indexes do not include this parameter. A strong quadriceps muscle is associated with a lower risk of death [22]. This is of course not explained by the BMI and it may explain the obesity paradox. Handgrip strength predicts outcomes in intensive care unit patients including outcomes such as death and paresis [23]. This causality relation is also independent of the BMI. For this reason a new indicator must be developed in order to capture these correlations and causal relations and predict the outcome of these experiments. Handgrip weakness is predictive of death in critical ill patients [23]. Handgrip weakness in midlife predicts health limitations 25 years later [24]. Experimental research [27] found that handgrip strength predicts possible disability in older man. Experiments in [28] found that handgrip strength is a predictor of mortality and morbidity, in man and woman, predicting up to 5 diseases. Handgrip strength predicts mobility limitations in older people [29]. Handgrip strength is a predictor in the outcome of the renal disease [30]. All these conclusions cannot be predicted from BMI, Broca index, ponderal index, or ABSI or SBSI, therefore a new model must be created which explains these experiments by incorporating their causality.

It is possible to incorporate in a formula GGBMI (grip strength generalization of BMI) the outcome and the causality proven by all these experiments:

$$\mathrm{GGBMI}(\mathrm{weight},\ \mathrm{height},\ grip\_strength) = \frac{Weight}{Height^{1+\frac{grip\_strength}{54}}}$$

The grip strength is correlated to the overall body strength, muscles and health status. For this reason, this formula makes the difference between muscle and fat and between

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

large frame, which is correlated to the grip strength and small frame and between healthy and not healthy. Indirectly through grips strength this formula, quantifies age and work type and volume because those have an impact on grip strength and correlates with it. These factors are quantified indirectly through grip strength, which is essential in types of professions where the body strength develops overall. The idea and logic behind my formula starts from the observation that the power of Height is a parameter, which controls both the value of the GGBMI (Grip strength generalization of body mass index) as well as the variation of GGBMI with the height. The optimal value is not always 2. Two is an approximation, which is reasonably good for people who are similar to those for which the BMI was determined as a statistic, but the power two is not always optimal for the modern sedentary person, or for people who do not perform physical work and BMI is not proper also for the opposite, the people who are very strong, athletic, muscular. The BMI was developed in the 19^{th} century based on statistics of the people who lived at that time, many of which were performing very heavy physical work, were leaner and stronger, shorter and younger than the population is today. We need to find a power of Height as a function of grip strength, which better solves the problem of accounting for the muscular development and using it to create a more general formula where BMI is a particular case. Such a formula would be more suited for the population of today instead of using constant 2 as a power of height. We can define an indicator

$$\frac{grip\_strength}{average\ grip\ strength}\ comparable\ with\ 1, for\ the\ average\ person$$

. In this case the new formula is similar to classical BMI and for this reason, the classical BMI is a particular case of my formula in the physiological and mathematical sense.
A strong male, but which is not trained in sport has handgrip strength up to 57 kg. according to research. The idea of the new method is to re-define the limits of normal weight range by developing a function where instead of having height at power two, there is a power, function of the strength of the handgrip, where for the normal strong people, people who are strong naturally but do not train in sport, there is a function similar to BMI, because $\frac{Grip\ Strength}{54}\ would\ be\ aproximatively\ 1$ and $1+\frac{grip_{strengt}}{54}$ $would\ be\ aproximatively\ 2\ and$ $\text{Height}^{1+\frac{grip_{strength}}{54}}$ would be aproximatively Height^2 $like\ in\ the\ classic\ BMI\ which\ is\ a\ particular\ case\ of\ my\ formula.\ This\ makes\ sense\ because$ BMI was developed based on statistics from a time and society where most people were doing heavy physical work, so the choice of 54 is justified logically and experimentally. In cases where the grip is stronger, like in the case of athletes, and people who practice sport, the power of H is greater than two because $\frac{grip\_strength}{54}$ would be greater than 1 and $1+\frac{grip\_strength}{54}$ would in this case be greater than 2. In this case, my function predicts a larger acceptable weight than BMI would. For cases where the grip strength is smaller than 54 kg, $\frac{\text{grip\_strength}}{54}$ is smaller than 1 and $1+\frac{grip\_strength}{54}$ is smaller than 2.
Test cases:
For a grip = 54 kg, at height =1.8 m and a weight = 80 kg, the formula returns a BMI 24.69 which is at the limit of the normal BMI. If we double the grip strength to 108 kg, the formula predicts an acceptable weight of up to 140kg. Compared to grip strength this weight would not be higher than the weight of the average person compared to their grip strength. There are studies for the grip of normal people and they suggest that few untrained people have a grip comparable to their weight and most of them have perhaps, if in good condition, 50-80% of their body weight. There are no studies on the grip strength of athletes as far as I know, however based on my own experience, I think for grip strength of 108 kg, a body weight of 140 kg would be to high. Statistical studies are needed and my analysis and simulation may orient such statistical studies. For this reason, I think a better formula would make a smaller

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

rate of increase in acceptable weight with grip strength. More studies are needed but this research is specifically intended to help such studies. Therefore a new formula would describe the optimal relation of grip and normal weight limits better.

$$GGBMI = \frac{Weight}{Height^{1+\,0.5+0.5*\frac{grip\_strength}{54}}} = \frac{Weight}{Height^{1.5+0.5*\frac{grip\_strength}{54}}}$$

This formula predicts a maximum normal weight of up to 108kg for grip strength of 108kg. This formula is correct in my view for ordinary people and for most athletes and sets a higher standard of strength and athleticism relative to weight compared to average people, few have grip strength equal to their weight. For the athletes who develop in particular their grip such as gymnasts or people who train their grip specifically, then the ideal weight formula would need a different form because in their case the grip strength does not correlate in the same way with the strength in other parts of the body. For the case of people who practice sports where grip strength is critical or train the grip strength specifically then a more correct formula would be

$$GGBMI = \frac{weight}{Height^{1+\,0.5+0.5*\frac{grip\_strength}{weight}}} = \frac{weight}{Height^{1.5+0.5*\frac{grip\_strength}{weight}}}$$

This formula would predict a maximum normal weight of 87kg for somebody with handgrip strength of 108kg, a height of 1.8m. I believe this is correct in general for boxers and wrestlers and gymnasts and it predicts normal weight in the sense of normal body fat percentage, but the competitive weight of world class gymnasts is lower than the weight predicted by this formula. For a 1.7 m athlete with handgrip strength of 108lg this formula would predict a maximum normal weight of 79kg, which is reasonable, but of course the optimal competitive weight may be lower. Even at 79kg such athlete would not be fat or overweight.

It is possible to find an even more general formula

$$GGBMI = \frac{Weight}{Height^{1+\,c1+c2*\frac{grip\_strength}{54}}}$$

Perhaps the average male today does not have a handgrip strength of 54kg and this has declined over the last decades as the amount of physical work and the level of testosterone had declined. Perhaps the average male today has a handgrip strength of about 45 – 50kg. We could use a 47 kg as average and the formula becomes

$$GGBMI(weight, height, grip\_strength) = \frac{Weight}{Height^{1+0.5+0.5*\frac{grip\_strength}{47}}}$$

Using 54 instead of 47 promotes a more lean standard, a better standard, where low strength means a lower maximum weight than BMI would predict while high strength means higher weight limit than BMI would predict. Use of 47 is more in line with a lower standard, similar to that of BMI. However, the real BMI made through statistical data from the 19th century was based on people who had a stronger grip than the average people today because most were performing heavy physical work, as heavy as few perform today when there is technology to decrease the heavy loads of work and there are work protection laws. The choice of 54 kg grip strength seems stronger than the average male for our time but it is in line with the historical base of the statistics behind the BMI. 54kg grip strength is not very much for athletes, I would say it is modest for an athlete who uses the hands in sport or in exercise.

For woman, I chose the constant 38 instead of 54, so the grip strength would be divided by 38 as in $\frac{grip\_strength}{38}$ and we find the formula

$$GGBMI = \frac{Weight}{Height^{1+\frac{grip\_strength}{38}}}$$

The use of the grip in the BMI formula could be combined with an anthropometric proportion $\frac{\text{Chest} - 10\text{H}}{\text{waist}}$, as a factor in the power of H. The use of the $\frac{\text{Chest} - 10\text{H}}{\text{waist}}$ factor is explained in (godescu, A. The Anthropometric Generalization of the Body Mass Index) [2] where I introduce the first generalizations of BMI, which makes the difference between fat and muscles, body frame and shape. The idea behind the formula is that the higher the $\frac{\text{Chest}}{\text{waist}}$ proportion, the more athletic and lean the shape of a person is, because it means larger chest than waist, which is the way athletic body shape is represented. All the obese people regardless if they have developed large muscles or not, have a larger difference between waist and chest than in the case of athletic people or in the case of people with normal weight. Of course those who are obese but have weak upper body part muscles have smaller chest/wait ratio compared to the obese athletes who have large chest muscles too. Then I used the $\frac{\text{Chest} - 10\text{H}}{\text{waist}}$ ratio because the chest is usually larger than the waist in average people and in order to keep the value of the ratio 1 for the average person, I determined that the chest is usually larger with 10xHeight than the waist. I defined $\frac{\text{Chest} - 10\text{H}}{\text{waist}}$ as an indicator of body shape and obesity and factored it with the classic BMI. We can use specific constants for each size as I show in [2]. This formula is not established and in fact it is my own observation and generalization, which I believe is correct. Perhaps more studies are needed to establish the constant, but I found 10xHeight an appropriate relation between Height, chest and waist in normal people. This is a new conclusion and perhaps more studies are needed to confirm it but it seems a good relation. The value and correctness of findings of this analysis do not depend of this relation, this is only an additional observation. Other methods to determine the constant in the $\frac{\text{Chest} - \text{C*H}}{\text{waist}}$ ratio, I developed in [2]. Using the same principle of quantification and factoring of strength in a generalization of BMI using the $\frac{grip\_strength}{54}$ ratio, as a measure of the strength of the person compared to the strength of strong people who are not trained in sport, then I used the expression $1 + \frac{grip\_strength}{54} \times \frac{\text{Chest} - 10\text{H}}{\text{waist}}$ as a power of Height instead of the power of 2 because $\frac{grip\_strength}{54} \times \frac{\text{Chest} - 10\text{H}}{\text{waist}}$ would be about 1 for normal people who perform physical work, the type of person for which the BMI was determined in the 19th century. So the classic BMI is a particular case of my formula. The formulae becomes for males

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

$$\mathrm{GGBMI} = \frac{Weight}{Height^{1+\frac{grip\_strength}{54}\times\frac{Chest-10H}{waist}}}$$

or with the improvement discussed above

$$\mathrm{GGBMI} = \frac{Weight}{Height^{1.5+0.5*\frac{grip\_strength}{54}\times\frac{Chest-10H}{waist}}}$$

and for athletes or people who train the grip strength

$$\mathrm{GGBMI} = \frac{Weight}{Height^{1.5+0.5*\frac{grip\_strength}{weight}\times\frac{Chest-10H}{waist}}}$$

or with a lower standard for male

$$\mathrm{GGBMI} = \frac{Weight}{Height^{1+\frac{grip\_strength}{47}\times\frac{Chest-10H}{waist}}}$$

and for woman

$$\mathrm{GGBMI} = \frac{Weight}{Height^{1+\frac{grip\_strength}{38}\times\frac{Chest-10H}{waist}}}$$

Like in engineering we can try to derive several formulae based on this new method and test which is the best through future practical and experimental studies.

Observing that $\frac{\mathrm{Chest} - 10\mathrm{H}}{\mathrm{waist}}$ ratio is about 1 for average people, higher than 1 for athletic people and lower than 1 for overweight and obese, it is possible to define a new generalization of BMI using anthropometric values as

$$\mathrm{AGBMI} = \frac{Weight}{Height^{2\times\frac{Chest-10\times Height}{waist}}}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

My numerical examples and simulations for anthropometric generalizations of BMI can be found in "The anthropometric generalization of body mass index" [2].

In a similar way, the fraction $\frac{grip\_strength}{54}$ is about 1 for stronger than average males who do not perform a strength sport. It is possible to define a generalization of BMI function of grip strength, making the difference between muscles, large frame and fat as

$$\text{GGBMI} = \frac{Weight}{Height^{2\times\frac{grip\_strength}{54}}}$$

and using a slower decrease of BMI with the grip strength

$$\text{GGBMI} = \frac{Weight}{Height^{2\times(0.5+0.5\times\frac{grip_{strengt}}{54})}}$$

Using an analogic idea, it is possible to develop a formula for athletes or people who develop the strength of their grip through special exercises. The explanation is given above.

$$\text{GGBMI} = \frac{Weight}{Height^{2\times(0.5+0.5\times\frac{grip_{strengt}}{weight})}}$$

Test example: for height = 1.7m, weight = 70kg, grip strength 54 kg, the formula predicts a maximum normal weight of 65 kg, so a leaner standard compared to BMI and Broca. For a stronger grip, like 108 kg, the formula predicts up to 84 kg.

The formula for females would be

$$\text{GGBMI} = \frac{Weight}{Height^{2\times\frac{grip\_strength}{38}}}$$

Or assuming the grip strength of the average male is 47kg, then $\frac{grip\_strength}{47}$ is about 1.

It is possible to define a generalization of BMI function of grip strength, making the difference between muscles, large frame and fat as

$$\text{GGBMI} = \frac{Weight}{Height^{2\times\frac{grip\_strength}{47}}}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

And for females $\mathrm{GGBMI} = \dfrac{Weight}{\mathrm{Height}^{2\times\frac{\mathrm{grip\_strength}}{33}}}$

If $1 + \left(\dfrac{grip\_strength}{54} \times \dfrac{Chest - 10H}{waist}\right)$ is about 2 for average people, then it is possible to define a body mass anthropometric and grip strength index as

$$\mathrm{AGGBMI} = \frac{Weight}{Height^{1+\frac{grip\_strength}{54}\times\frac{Chest-10\times Height}{waist}}}$$

Because $\left(1 + \dfrac{grip\_strength}{54}\right) \times \dfrac{chest - 10H}{waist}$ is about 2 for an average young male in good physical condition then we can define an anthropometric and grip strength generalization of the BMI as

$$\mathrm{AGBMI} = \frac{Weight}{Height^{\left(1+\frac{grip\_strength}{54}\right)\times\frac{chest-10Height}{waist}}}$$

Based on the same principles and [2] we can build also the following formula

$$\mathrm{AGBMI} = \frac{Weight}{Height^{\frac{chest-10\times Height}{waist}\div\frac{grip\_strength}{54}}}$$

And based on the discussion above

$$\mathrm{AGBMI} = \frac{Weight}{Height^{\frac{chest-10\times Height}{waist}\div(0.5+0.5*\frac{grip\_strength}{54})}}$$

And for athletes in sports where grips strength is essential

$$\mathrm{AGBMI} = \frac{Weight}{Height^{\frac{chest-10\times Height}{waist}\div(0.5+0.5*\frac{grip\_strength}{weight})}}$$

Assuming a male in good physical condition has a grip strength of about 54 kg, then $\dfrac{grip\_strenght - 54}{54}$ is 0 for the an active male in good physical condition performing and a new indicator could be defined as

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

$$\text{GGBMI} = \frac{weight}{H^{2+\frac{grip_{strengt} - 54}{weight}}}$$

For the previous test case, height = 1.7m, grip strength = 105 kg, the formula predicts a maximum weight of 97kg. Indeed it is high, but we may see that most people do not have a grip strength higher than their body weight, indeed, for untrained people, this is very rare. In this case, if the grip strength is average high untrained, 54kg then the result is the standard BMI formula, and this proves the standard BMI is a particular case of my new formula, which is a generalization of BMI. It is possible to develop a optimal weight equation using 1.8 instead of 2, the reason is explained in [2].

$$\frac{weight}{H^{1.8+\frac{grip_{strengt} - 54}{weight}}} - 25 = 0$$

Which is the best formula, depends on the person and if the person is an athlete, it depends also on the sport to some extent, if we want high precision. Any of these formulae is better than the BMI alone and there is a lot of evidence, in some cases it is better by a large margin. These formulae are aimed also to guide statistical studies at larger scale and these studies will show the advantages of each formula over the BMI and which is better in which circumstance.

Division by weight or grip strength may seem arbitrary to some readers but it is a natural and common way to represent the strength of an athlete.

Normalization could be obtained through division by 100 and we obtain a smaller factor related to the grip strength. I consider the previous formula better, but there is also the possibility of division by 100 instead by division with 54 and then

$$\text{AGGBMI} = \frac{weight}{H^{2+\frac{grip\_strength - 54}{100}}}$$

Engineering an optimal formula is also achieved through trial and error. I developed and tested also formula developed based on similar principles such as

$$\text{AGBMI}=\frac{weight}{2 \times \frac{chest - 10 \times Height}{waist} + \frac{grip\_strength - 54}{100}}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

$$\text{AGBMI} = \frac{Weight}{Height^{2\times\frac{chest-10\times Height}{waist}+\frac{grip\_strenght-54}{54}}}$$

$$\text{AGBMI} = \frac{Weight}{Height^{2\times\frac{chest-10\times Height}{waist}\times\frac{grip\_strenght}{54}}}$$

$$\text{GGBMI} = \frac{Weight}{Height^{2+\frac{grip\_strength-54}{100}}}$$

$$\text{AGBMI} = \frac{Weight}{Height^{2+\frac{chest-10\times Height}{waist}\times\frac{grip\_strength-54}{100}}}$$

$$\text{AGBMI} = \frac{Weight}{Height^{2\times\frac{chest-10\times Height}{waist}+\frac{chest-10\times Height}{waist}\times\frac{grip\_strength-54}{100}}}$$

Bending a bar

Bending a flexible bar is an exercise, which can easily be performed for testing medical purposes and interpreted using the formulae developed by me, in a medical office or at home or in a gym or sport center, it requires a cheap bar of length about 50 cm which the subject bends using the strength of the upper body. It has an advantage over the grip method because bending a bar involves the large muscles of the upper part of the body not only the grips strength and it is an indicator of the development of the muscles of the upper part of the body and indicates the weight of those muscles which influences the computation of my generalization of BMI. Bending a bar had been a strong man show before the age of Olympic weightlifting, it was often performed in circus or exhibitions. It uses grip, forearm, biceps, triceps, pectoral (chest), deltoid (shoulder). This is a good indicator of upper body strength, muscular mass and muscular volume. Such bars can easily be purchased from web stores or from sport stores. There are no studies on the average person strength at bending a flexible strength bar, therefore I will use vales consistent with my observations. I think the average young male strength at such exercise may be around 40kg. the formulae would be similar to those developed above for the grip strength index, analogic. As a consequence of this assumption $1+\frac{grip\_strength}{40}$ would be about equal to 2 for the average healthy and active male. Therefore it is possible to develop and test the following formulae:

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

The strength generalization of body mass index

$$SGBMI(\text{weight}, \text{height}, \textit{bending\_bar\_strength}) = \frac{\text{Weight}}{\text{Height}^{1+\frac{\text{bending\_bar\_strength}}{40}}}$$

We analyze this formula in the following way. For somebody who is able to bend a bard of strength 40kg, the formula becomes $SGBMI = \frac{\text{weight}}{\text{height}^{2.0}}$. which shows the classic BMI is a particular case of my formula. For a weaker male who can bend a bar which is equivalent to 35 kg push we find the maximum normal weight determined by my formula is smaller than that of the standard BMI, it is 75kg. (of course the strength is expressed by a force in this case not by a weight but these strength bars for twisting are advertised with the equivalent in weight lifting and I use this measure, because I did not make myself the bars, so I cannot offer a different metric)

For stronger people, for example with strength = 50kg or equivalent for that move, the maximum normal weight predicted by my formula is 93 kg. There is no previous research and no statistical study, but in my view it is to high, so I believe a formula with a slower decrease of BMI with strength. (SGBMI=strength generalization of body mass index)

$$SGBMI(\text{weight}, \text{height}, \textit{bending\_bar\_strength}) = \frac{\text{Weight}}{\text{Height}^{1+\sqrt{\frac{\textit{bending\_bar\_strength}}{40}}}}$$

This formula would predict a maximum normal weight of 86kg which is better.

A normalization on weight which is very intuitive, strength on weight is a very common parameter of the strength of an athlete so the following formula follows:

$$SGBMI(\text{weight}, \text{height}, \textit{bending\_bar\_strength}) = \frac{\text{Weight}}{\text{Height}^{1.5+\frac{\textit{bending\_bar\_strength}}{\textit{weight}}}}$$

For bar bending strength of 40kg, this formula would find the BMI as a particular case, which I think it is correct. Experimentation and experimental study would be needed. For strength on this move equivalent to 50kg, the maximum predicted weight is 84, for 60 kg is 89kg, for 80 kg strength, the maximum normal weight would be according to this formula 97kg. for 120kg bar bending strength, maximum predicted weigh is 113kg. Bending a bar is harder than overhead lifting because the nature of the move. Based on mechanics it is as hard as dumbbell bench press with that weight, so 120kg is very much on that mechanics. More experiments are needed including designs and test, but the values make sense. An ideal weight formula developed would look like

$$\frac{\text{Weight}}{\text{Height}^{1.4+\frac{\textit{bending\_bar\_strength}}{\textit{weight}}}} - 25 = 0$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 August 2020 doi:10.20944/preprints202008.0211.v1

In the same way similar to previous formulae other formulae with the same symmetry could be developed in an analogue way. It may be possible to increase the power of Height in a different way than linear with the strength at bending a bar but based on my observations it is correct to increase it in a linear way because the strength at bending a bar correlates with the upper body strength not just with the grip.

$$SGBMI = \frac{weight}{H^{2+\frac{bending\_bar\_strength - 40}{weight}}}$$

This formula would predict as much as 119kg maximum normal weight for a 120kg bar crunch. Of course, it would be correct to use a force not weight but this is how bars are sold, and we can make an equivalent to a lifting move such as dumbbell bench press where the weights are measured in kg. The advantage of this move is that could be tested with very simple equipment, a short 50cm bar in a medical office or at home. It is certain, my formula is a lot better than BMI in making the difference between muscle and fat. For a 40kg strength on this exercise the formula is similar to the standard BMI, which is a particular case. This formula has the BMI as a particular case but works in both ways, for stronger people it allows higher weigh but for weaker people it allows less weight than the classic BMI. It is possible to define SABMI = Strength and anthropometric generalization of BMI

$$SAGBMI = \frac{Weight}{Height^{1+\frac{bending\_bar\_strength}{30}\times\frac{Chest - 10H}{waist}}}$$

Other formulae I analyzed are

$$SGBMI = \frac{Weight}{Height^{2\times\frac{bending\_bar\_strength}{30}}}$$

$$SAGBMI = \frac{Weight}{Height^{1+\frac{bending\_bar\_strength}{30}\times\frac{Chest - 10\times Height}{waist}}}$$

$$SAGBMI = \frac{Weight}{Height^{\left(1+\frac{bending\_bar\_strength}{30}\right)\times\frac{chest - 10Height}{waist}}}$$

Discussion

When scientists research various substances with pharmacological applications, they develop various substances, then test them in laboratory, experimentally and in trials. In the same way I develop a number of formulae based on some ideas, experiments cited and principles I developed, them test the formulae with test cases, simulate it and present it so that people who design experimental studies can verify these formulae in a large number of cases, on statistical basis. These formulae explain also the well known experiments [21][23][24][25][26][27][28][29][30][31][32][33][34][35][37][38][39][40][41][16][17][18][19][20][22][36] and incorporate their conclusion in a new formula which generalizes the BMI.

Conclusion

The formula developed through my analysis solve the problem of quantification of muscles in the body weight and making the difference between muscles and fat in a simple way, which can easily be tested and interpreted at home or in a medical office or gym or sport club. These formula explain many important experiments predicting health outcomes which are not predicted by the BMI such as those described in publications such as [21][23][24][25][26][27][28][29][30][31][32][33] [34][35][37][38][39][40][41][16][17][18][19][20][22][36], quantify the causality found in these experiments and make possible the design of new experiments based on these parameters. The methods I propose in this analysis represent a generalization of the BMI which can be found as a special case for normal people. This along with my anthropometric generalization of BMI [2] are the first and only generalization of the BMI solving its limitations described above. In [2] I show why no other formula achieved these goals before.

Bibliography

1. Adolphe Quetelet. 1842. A treatise on Man and the Development of His Faculties.

2. godescu, A. The Anthropometric Generalization of the Body Mass Index. *Preprints* **2020**, 2020070662 (doi: 10.20944/preprints202007.0662.v1).

3. Nevill, A.M., Stewart, A.D., Olds, T. and Holder, R. (2006), Relationship between adiposity and body size reveals limitations of BMI. Am. J. Phys. Anthropol., 129: 151-156. doi:10.1002/ajpa.20262

4. Krakauer NY, Krakauer JC (2012) A New Body Shape Index Predicts Mortality Hazard Independently of Body Mass Index. PLoS ONE 7(7): e39504. https://doi.org/10.1371/journal.pone.0039504

5. Keys A, Karvonen N, Kimura N, Taylor HL. Indices of relative weight and obesity. J Chronic Dis 1972;25:329–43

6. World health organization, Global Health Risks, Mortality and burden of disease attributable to selectable major risks (2009) https://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf

7. Heymsfield, S., Scherzer, R., Pietrobelli, A. *et al.* Body mass index as a phenotypic expression of adiposity: quantitative contribution of muscularity in a

population-based sample. *Int J Obes* **33,** 1363–1373 (2009). https://doi.org/10.1038/ijo.2009.184

8. Abdominal Obesity and the Metabolic Syndrome: Contribution to Global Cardiometabolic Risk, Jean-Pierre Després , Isabelle Lemieux , Jean Bergeron , Philippe Pibarot , Patrick Mathieu , Eric Larose , Josep Rodés-Cabau , Olivier F. Bertrand , and Paul Poirier

9. Sui X, LaMonte MJ, Laditka JN, et al. Cardiorespiratory Fitness and Adiposity as Mortality Predictors in Older Adults. *JAMA.* 2007;298(21):2507–2516. doi:10.1001/jama.298.21.2507

10. Jacobs EJ, Newton CC, Wang Y, et al. Waist Circumference and All-Cause Mortality in a Large US Cohort. *Arch Intern Med.* 2010;170(15):1293–1301. doi:10.1001/archinternmed.2010.201

11. Annemarie Koster, Michael F. Leitzmann, Arthur Schatzkin, Traci Mouw, Kenneth F. Adams, Jacques Th. M. van Eijk, Albert R. Hollenbeck, Tamara B. Harris, Waist Circumference and Mortality, *American Journal of Epidemiology*, Volume 167, Issue 12, 15 June 2008, Pages 1465–1475, https://doi.org/10.1093/aje/kwn079

12. James R. Cerhan, Steven C. Moore, Eric J. Jacobs, Cari M. Kitahara, Philip S. Rosenberg, Hans-Olov Adami, Jon O. Ebbert, Dallas R. English, Susan M. Gapstur, Graham G. Giles, Pamela L. Horn-Ross, Yikyung Park, Alpa V. Patel, Kim Robien, Elisabete Weiderpass, Walter C. Willett, Alicja Wolk, Anne Zeleniuch-Jacquotte, Patricia Hartge, Leslie Bernstein, Amy Berrington de Gonzalez, A Pooled Analysis of Waist Circumference and Mortality in 650,000 Adults,
Mayo Clinic Proceedings, Volume 89, Issue 3,2014, Pages 335-345, ISSN 0025-6196, https://doi.org/10.1016/j.mayocp.2013.11.011.
(http://www.sciencedirect.com/science/article/pii/S0025619613010409)

13. . Carmienke, S., Freitag, M., Pischon, T. *et al.* General and abdominal obesity parameters and their combination in relation to mortality: a systematic review and meta-regression analysis. *Eur J Clin Nutr* **67,** 573–585 (2013). https://doi.org/10.1038/ejcn.2013.61

14. FENG, K., CHEN, L., HAN, S.-M. and ZHU, G.-J. (2012), Ratio of waist circumference to chest circumference is inversely associated with lung function in Chinese children and adolescents. Respirology, 17: 1114-1118. doi:10.1111/j.1440-1843.2012.02219.x

15. Anthony E. Coy, Jeffrey D. Green, Michael E. Price,
Why is low waist-to-chest ratio attractive in males? The mediating roles of perceived dominance, fitness, and protection ability, Body Image,
Volume 11, Issue 3, 2014, Pages 282-289, ISSN 1740-1445,
https://doi.org/10.1016/j.bodyim.2014.04.003.
(http://www.sciencedirect.com/science/article/pii/S1740144514000369)

16. Juan José Soler-Cataluña, Lourdes Sánchez-Sánchez, Miguel Ángel Martínez-García, Pilar Román Sánchez, Emmanuel Salcedo, Miriam Navarro,
Mid-Arm Muscle Area Is a Better Predictor of Mortality Than Body Mass Index in COPD,
Chest, Volume 128, Issue 4, 2005, Pages 2108-2115, ISSN 0012-3692,
https://doi.org/10.1378/chest.128.4.2108.
(http://www.sciencedirect.com/science/article/pii/S001236921552610X)

17. Preethi Srikanthan, Arun S. Karlamangla, Relative Muscle Mass Is Inversely Associated with Insulin Resistance and Prediabetes. Findings from The Third National Health and Nutrition Examination Survey, *The Journal of Clinical Endocrinology & Metabolism*, Volume 96, Issue 9, 1 September 2011, Pages 2898–2903, https://doi.org/10.1210/jc.2011-0435

18. Preethi Srikanthan, Tamara B. Horwich, Chi Hong Tseng, Relation of Muscle Mass and Fat Mass to Cardiovascular Disease Mortality, The American Journal of Cardiology, Volume 117, Issue 8, 2016, Pages 1355-1360, ISSN 0002-9149, https://doi.org/10.1016/j.amjcard.2016.01.033. (http://www.sciencedirect.com/science/article/pii/S0002914916301552)

19. Konstantinos A. Volaklis, Martin Halle, Christa Meisinger, Muscular strength as a strong predictor of mortality: A narrative review, European Journal of Internal Medicine, Volume 26, Issue 5, 2015, Pages 303-310, ISSN 0953-6205, https://doi.org/10.1016/j.ejim.2015.04.013. (http://www.sciencedirect.com/science/article/pii/S0953620515001089)

20. Ruiz Jonatan R, Sui Xuemei, Lobelo Felipe, Morrow James R, Jackson Allen W, Sjöström Michael et al. Association between muscular strength and mortality in men: prospective cohort study *BMJ* 2008; 337 :a439

21. Handgrip strength and mortality in the oldest old population: the Leiden 85-plus study Carolina H.Y. Ling, Diana Taekema, Anton J.M. de Craen, Jacobijn Gussekloo, Rudi G.J. Westendorp, Andrea B. Maier CMAJ Mar 2010, 182 (5) 429-435; DOI: 10.1503/cmaj.091278

22. Kentaro Kamiya, Takashi Masuda, Shinya Tanaka, Nobuaki Hamazaki, Yuya Matsue, Alessandro Mezzani, Ryota Matsuzawa, Kohei Nozaki, Emi Maekawa, Chiharu Noda, Minako Yamaoka-Tojo, Yasuo Arai, Atsuhiko Matsunaga, Tohru Izumi, Junya Ako, Quadriceps Strength as a Predictor of Mortality in Coronary Artery Disease, The American Journal of Medicine, Volume 128, Issue 11, 2015, Pages 1212-1219, ISSN 0002-9343, https://doi.org/10.1016/j.amjmed.2015.06.035. (http://www.sciencedirect.com/science/article/pii/S0002934315005860)

23. O'Brien JM, Hoffmann SP, Phillips G, Garland A, Finley JC, Almoosa K, Hejal R, Wolf KM, Lemeshow S, Connors AF, Marsh CB, Midwest Critical Care Consortium. Acquired weakness, handgrip strength, and mortality in critically ill patients. Am J Respir Crit Care Med. 2008 Aug;178(3) 261-268. doi:10.1164/rccm.200712-1829oc. PMID: 18511703.

24. Rantanen T, Guralnik JM, Foley D, et al. Midlife Hand Grip Strength as a Predictor of Old Age Disability. *JAMA.* 1999;281(6):558–560. doi:10.1001/jama.281.6.558

25. Innes, E. (1999), Handgrip strength testing: A review of the literature. Australian Occupational Therapy Journal, 46: 120-140. doi:10.1046/j.1440-1630.1999.00182.x

26. Visnapuu M, Jürimäe T. Handgrip strength and hand dimensions in young handball and basketball players. *J Strength Cond Res*. 2007;21(3):923-929. doi:10.1519/1533-4287(2007)21[923:HSAHDI]2.0.CO;2

27. S Giampaoli, L Ferrucci, F Cecchi, C Lo Noce, A Poce, F Dima, A Santaquilani, M F Vescio, A Menotti, Hand-grip strength predicts incident disability in non-disabled older men., *Age and Ageing*, Volume 28, Issue 3, May 1999, Pages 283–288, https://doi.org/10.1093/ageing/28.3.283

28. Cheung, C., Nguyen, U.D.T., Au, E. *et al.* Association of handgrip strength with chronic diseases and multimorbidity. *AGE* **35,** 929–941 (2013). https://doi.org/10.1007/s11357-012-9385-y

29. Sallinen, J., Stenholm, S., Rantanen, T., Heliövaara, M., Sainio, P. and Koskinen, S. (2010), Hand‐Grip Strength Cut Points to Screen Older Persons at Risk for Mobility Limitation. Journal of the American Geriatrics Society, 58: 1721-1726. doi:10.1111/j.1532-5415.2010.03035.x

30. Yu-Tzu Chang, Hung-Lien Wu, How-Ran Guo, Ya-Yun Cheng, Chin-Chung Tseng, Ming-Cheng Wang, Ching-Yuang Lin, Junne-Ming Sung, Handgrip strength is an independent predictor of renal outcomes in patients with chronic kidney diseases, *Nephrology Dialysis Transplantation*, Volume 26, Issue 11, November 2011, Pages 3588–3595, https://doi.org/10.1093/ndt/gfr013

31. Trosclair, D[1]; Bellar, D[1]; Judge, L, W[2]; Smith, J[1]; Mazerat, N[1]; Brignac, A[1] Hand-Grip Strength as a Predictor of Muscular Strength and Endurance, Journal of Strength and Conditioning Research: March 2011 - Volume 25 - Issue - p S99 doi: 10.1097/01.JSC.0000395736.42557.bc

32. Zaccagni, L.; Toselli, S.; Bramanti, B.; Gualdi-Russo, E.; Mongillo, J.; Rinaldo, N. Handgrip Strength in Young Adults: Association with Anthropometric Variables and Laterality. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4273.

33. Christian M. Günther, Alexander Bürger, Markus Rickert, Alexander Crispin, Christoph U. Schulz, Grip Strength in Healthy Caucasian Adults: Reference Values, The Journal of Hand Surgery, Volume 33, Issue 4, 2008, Pages 558-565, ISSN 0363-5023, https://doi.org/10.1016/j.jhsa.2008.01.008. (http://www.sciencedirect.com/science/article/pii/S0363502308000129)

34. Ercan Cetinus, Mehmet Akif Buyukbese, Murat Uzel, Hasan Ekerbicer, Ahmet Karaoguz, Hand grip strength in patients with type 2 diabetes mellitus, Diabetes Research and Clinical Practice, Volume 70, Issue 3, 2005, Pages 278-286, ISSN 0168-8227, https://doi.org/10.1016/j.diabres.2005.03.028. (http://www.sciencedirect.com/science/article/pii/S016882270500118X)

35. A.A. Sayer, H.E. Syddall, E.M. Dennison, H.J. Martin, D.I.W. Phillips, C. Cooper, C.D. Byrne, Grip strength and the metabolic syndrome: findings from the Hertfordshire Cohort Study, *QJM: An International Journal of Medicine*, Volume 100, Issue 11, November 2007, Pages 707–713, https://doi.org/10.1093/qjmed/hcm095

36. Serpil Savaş, Banu Kale Köroğlu, Hasan Rifat Koyuncuoğlu, Ertuğrul Uzar, Hakan Çelik, Numan Mehmet Tamer, The effects of the diabetes related soft tissue hand lesions and the reduced hand strength on functional disability of hand in type 2 diabetic patients, Diabetes Research and Clinical Practice, Volume 77, Issue 1, 2007, Pages 77-83, ISSN 0168-8227, https://doi.org/10.1016/j.diabres.2006.10.020. (http://www.sciencedirect.com/science/article/pii/S0168822706004918)

37. Arch G. Mainous, Rebecca J. Tanner, Stephen D. Anton, Ara Jo, Grip Strength as a Marker of Hypertension and Diabetes in Healthy Weight Adults, American Journal of Preventive Medicine, Volume 49, Issue 6, 2015, Pages 850-858, ISSN 0749-3797, https://doi.org/10.1016/j.amepre.2015.05.025. (http://www.sciencedirect.com/science/article/pii/S0749379715002676)

38. P.L. Wander, E.J. Boyko, D.L. Leonetti, M.J. McNeely, S.E. Kahn, W.Y. Fujimoto, Greater hand-grip strength predicts a lower risk of developing type 2 diabetes over 10 years in leaner Japanese Americans, Diabetes Research and Clinical Practice, Volume 92, Issue 2, 2011, Pages 261-264, ISSN 0168-8227, https://doi.org/10.1016/j.diabres.2011.01.007. (http://www.sciencedirect.com/science/article/pii/S0168822711000088)

39. 88. Arvandi, M., Strasser, B., Meisinger, C. *et al.* Gender differences in the association between grip strength and mortality in older adults: results from the KORA-age study. *BMC Geriatr* **16,** 201 (2016). https://doi.org/10.1186/s12877-016-0381-4

40. Leong DP, Teo KK, Rangarajan S, et al. Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet. 2015;386(9990):266-273. doi:10.1016/S0140-6736(14)62000-6

41. Sasaki, Hideo & Kasagi, Fumiyoshi & Yamada, Michiko & Fujita, Shoichiro. (2007). Grip Strength Predicts Cause-Specific Mortality in Middle-Aged and Elderly Persons. The American journal of medicine. 120. 337-42. 10.1016/j.amjmed.2006.04.018.

42. Bandyopadhyay A. Body composition and hand grip strength in male brick-field workers. *Malays J Med Sci*. 2008;15(1):31-36.

43. McAuley, P. A. & Blair, S. N. Obesity paradoxes. *J Sports Sci.* **29**, 773–782 (2011).

44. Paul A. McAuley, Enrique G. Artero, Xuemei Sui, Duck-chul Lee, Timothy S. Church, Carl J. Lavie, Jonathan N. Myers, Vanesa España-Romero, Steven N. Blair, The Obesity Paradox, Cardiorespiratory Fitness, and Coronary Heart Disease, Mayo Clinic Proceedings, Volume 87, Issue 5, 2012, Pages 443-451, ISSN 0025-6196, https://doi.org/10.1016/j.mayocp.2012.01.013.

45. Després JP. Is visceral obesity the cause of the metabolic syndrome?. *Ann Med*. 2006;38(1):52-63. doi:10.1080/07853890500383895

46. Obesity Paradox Does Exist, Vojtech Hainer, Irena Aldhoon-Hainerová Diabetes Care Aug 2013, 36 (Supplement 2) S276-S281; **DOI:** 10.2337/dcS13-2023

47. Curtis JP, Selter JG, Wang Y, et al. The Obesity Paradox: Body Mass Index and Outcomes in Patients With Heart Failure. *Arch Intern Med.* 2005;165(1):55–61. doi:10.1001/archinte.165.1.55

48. Goyal A, Nimmakayala KR, Zonszein J. Is there a paradox in obesity?. *Cardiol Rev*. 2014;22(4):163-170. doi:10.1097/CRD.0000000000000004

49. Després, J., Lemieux, I. Abdominal obesity and metabolic syndrome. *Nature* **444,** 881–887 (2006). https://doi.org/10.1038/nature05488