1. Introduction

BMI is a simple index of weight to height which is commonly used to classify normal weight, overweight and obesity in adults. It has been used since long for quantifying the obesity. It is a number which is calculated by dividing the weight of the body (in kg) by square of the height (in meter). It is a cheap and easy method to access the body fat indirectly which may lead to many health’s related problems. Because calculation is based on height and weight only, so it is a very handy tool for both clinicians and general public. We have many tools for measuring the body fatness like skin fold thickness measurement(with calipers), underwater weighing, bioelectrical impedance, Dual energy X-ray Absorptiometry (DXA), and isotope dilution; but many of these have the problem of standardization across observer and machines which makes the whole process complicated.

The correlation between BMI and body fatness is fairly good but it is still affected by age, sex, profession, training, etc. For example:

- With the same BMI value, women tend to have more body fat than men.
- With the same BMI value, older people tend to have more body fat than younger adults.
- Highly trained athletes may have a high BMI because of increased muscles rather than increased body fat.

Anyone with a BMI over 25.00 would be treated as overweight and anyone with a BMI over 30.00 would be classified as obese according to Table 1. BMI is the one factor for giving the indication about some ailments or disease. Many instution or societies related to health recommend the following few factors to assess the risk for diseases: circumferences of waist, hip, thigh and neck, high blood pressure, physical inactivity etc.

List of the diseases associated with obese and overweight person’s is:

- Hypertension
- Dyslipidemia
- Type 2 diabetes
- Coronary heart disease
- Stroke
- Gallbladder disease
- Osteoarthritis
- Sleep apnea and respiratory problems
- Some cancers i.e. endometrial, breast and colorectal

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Along with being overweight or obese, the following conditions will put one at greater risk for many diseases specially heart disease:

- High blood pressure (hypertension)
- High LDL cholesterol (“bad” cholesterol)
- Low HDL cholesterol (“good” cholesterol)
- High triglycerides
- High blood glucose (sugar)
- Family history of premature heart disease
- Physical inactivity
- Cigarette smoking

Those who are considered obese (BMI >= 30) or overweight (25<BMI <30) with two or more risk factors (high BP or cholesterol etc) are advised to lose the weight.

2. Preliminaries

BMI is a measure of fat mass and muscles mass of human body determined by establishing relation between weight and height. It is measured by the formula: weight in kg divided by height square in meter.

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

Indirectly BMI value gives an idea about the body fat. On the basis of BMI score, World Health Organization (WHO) classifies a person into different categories of health as mentioned into Table 1.

| Classification       | Principal cut-off points | Additional cut-off points |
|----------------------|--------------------------|---------------------------|
| Underweight          | <18.50                   | <18.50                    |
| Severe Thinness      | <16.00                   | <16.00                    |
| Moderate Thinness    | 16.00-16.99              | 16.00-16.99               |
| Mild Thinness        | 17.00-18.49              | 17.00-18.49               |
| Normal Range         | 18.50-24.99              | 18.50-22.99               |
|                      | 23.00-24.99              |                           |
| Over weight          | >=25.00                  | >=25.00                   |
| Pre-obese            | 25.00-29.99              | 25.00-27.49               |
|                      |                          | 27.50-29.99               |
| Obese                | >=30.00                  | >=30.00                   |
| Obese class I        | 30.00-34.99              | 30.00-32.49               |
|                      |                          | 32.50-34.99               |
| Obese class II       | 35.00-39.99              | 35.00-37.49               |
|                      |                          | 37.50-39.99               |
| Obese class III      | >=40.00                  | >=40.00                   |

Besides BMI, some new and sophisticated technologies have now come up, but they are expensive and time consuming, and also not comfortable for general purpose reading and practice.

2.1 Limitations of Existing Notion of BMI.

1. BMI is not a perfect indicator of body fat because weight does not differentiate between lean body mass (bones, muscle, blood and water etc) and fat mass. It means that two persons having same BMI may have different percentage of body fat. With height and weight only, a single BMI formula cannot be good enough for all populations.

2. Persons with more muscles but less fat may give high value of BMI. Athletes like football players, wrestlers, weightlifters and boxers have more muscles than fat.

3. In older persons and others with reduced muscle mass, may underestimate the body fat.

4. Some athletes may be deemed underweight according to the BMI, specifically those long distance runners and other endurance sports people who have low body fat and lean muscle fiber.

3. Modified Notion of BMI: A Proposal

Besides the limitation mentioned in section-2 above, the following proposition reveals a major limitation and drawbacks of the existing notion of BMI.

3.1 Proposition

BMI of a senior or adult person cannot continue to be a fixed index.

Proof: For a senior or adult person, his/her height becomes static. In most of the cases the height does not change but weight keeps on changing with time. For a given adult or senior person, suppose that height = h (constant).

Therefore, \(\text{BMI} = \frac{w}{h^2}\)

Since w is not static with age in general, therefore BMI also is not static. Hence proved.

In existing formula of BMI, the parameter height (h) is in the denominator because of the logic that if two persons have equal mass then person having more height should have low BMI. We observe that this BMI is calculated on the basis of linear directional data whereas human body is three dimensional objects. The existing formula of BMI
is a good indicator in connection with majority of human population, but we need to introduce below a better indicator. We want to introduce the following logic:

If two persons have equal mass then person having more body surface area should have higher BMI. With this philosophy in mind we introduce a new notion of BMI, called by BMI type-2 or in short BMI-2. Before presenting the definition, we define another useful index called by FC index as below.

### 3.2 FC Index

FC index of a person stands an abbreviation for Four Circumferences (FC) together of the following:

- Circumference of Waist (fat depositing area of body) = \( c_1 \)
- Circumference of Hip (fat depositing area of body) = \( c_2 \)
- Circumference of Thighs (fat depositing area of body) = \( c_3 \)
- Circumference of Neck (fat depositing area of body) = \( c_4 \)

Thus \( FC = c_1 + c_2 + c_3 + c_4 \)

Clearly FC will be more for healthy or fatty person. Thus for a high FC we get the information that the person is not thin. But we don't get any confirmation from FC whether the person is healthy or not, and that is demerit of FC. However FC contributes to formulate BMI-2. In our future research work, we will explore the possibility of weighted sum of \( ci \) for computing FC as below:

\[
FC = w_1c_1 + w_2c_2 + w_3c_3 + w_4c_4
\]

where \( w_1 + w_2 + w_3 + w_4 = 1 \)

In fact, for this we will have to explore a method to unearth the individual contribution of each \( ci \) towards FC.

In the existing concept of BMI, cross-section elements are not considered although we claim that the cross-section elements could play a significant role in most of the cases. With this philosophy in mind, we need to define BMI in another way for better analysis and result. We define BMI in a different way now.

### 3.3 BMI-2

The BMI-2 of a person is defined by:

\[
BMI - 2 = \frac{(Weight \cdot FC)}{(Height)^2}
\]

Thus, \( BMI - 2 = BMI - 1 \cdot FC \).

To avoid confusion, we have renamed the existing BMI by BMI-1.

Suppose there are \( N \) persons. If we rank them in ascending order of BMI-1 and also BMI-2, we are likely to get two different sequences. We claim that the second sequence is more significant for medical results, analysis and diagnosis.

## 4. Case Study

We are calculating the modified BMI for men by including circumferences of waist, hip, thigh and neck into old formula of BMI.

### 4.1 Waist Circumference (WC)

A high WC is related to different types of diseases like type-2 diabetes, hypertension, dyslipidemia etc. Besides keeping eyes over BMI value, WC should also be monitored time to time. It gives an estimate of increased abdominal fat even when no change in BMI is observed. Table 2 describes WC.

**Table 2.** Waist circumference

| S.No. | Category       | Measurement in cm |
|-------|----------------|-------------------|
| 1     | Normal Range   | < 94 cm           |
| 2     | High Risk      | 94-101.9 cm       |
| 3     | Obese          | ≥ 102 cm          |

### 4.2 Waist-Hip Ratio (WHR)

The WHO Expert Consultation on WC and WHR was held in Geneva, Switzerland on 8–11 December 2008. Waist–hip ratio (the WC divided by the hip circumference) was suggested as an additional measure of body fat distribution. Table 3 discusses the norms of WHR.

**Table 3.** Waist-to-Hip Ratio (WHR) Norms

| Acceptable | Unacceptable |
|------------|--------------|
| <0.85      | 0.85-0.90    |
| 0.90-0.95  | 0.95-1.00    |
| ≥ 1.00     |              |

### 4.3 Thigh

According to the studies in Harvard Men’s Health Watch, that thigh circumference, measured where your thigh meets your butt, of about 62 centimeters or 24.4 inches was the most protective.

### 4.4 Neck

The neck size is as important as the waist size. According to the research, having fatty neck increases the risk factor for high blood pressure, high triglycerides and lower levels of
HDL. Scientists from the Department of Family Medicine, Faculty for Health Sciences, Ben-Gurion of the Negev, Israel, suggested the safe neck size not more than 37 centimeters.

4.5 Threshold/Cut-Off Values
Cut-off sizes of waist, hip, thigh and neck are 94 cm, 80 cm, 62 cm and 37 cm respectively. We have considered here the waist size of Europid people because of high upper limit of waist size among others. Table 4 summarizes the different threshold/cut-off values.

Table 4. Threshold values of different body-segments

| Body Segment | Cut-off size(cm) |
|--------------|------------------|
| Waist Size (c1) | 94(for Europid people) |
| Hip Size (c2) | 80(0.85x94) |
| Thigh Size (c3) | 62 |
| Neck Size (c4) | 37 |

4.6 Discussion
We have already observed that circumferences of waist (c1), hip (c2), thigh (c3) and neck (c4) are related to the health status. If any one of c1, c2, c3 or c4 goes beyond the threshold value, then person cannot be put into normal category of health.

In the Table 5, we have considered a case of an adult male with age 20, weight 80 kg and height 6 feet (1.83 meter). We have also considered here that weight may keep changing but height remains almost constant throughout life after certain stage of life. Suppose his circumferences of waist, hip, thigh and neck are 94 cm, 80 cm, 62 cm and 37 cm respectively. According to the old formula, his BMI value is 23.88(for weight 80 kg and height 1.83 meter).

It is generally observed that with time weight keeps on increasing. Suppose that man has managed to keep the values of c1, c2, c3 and c4 almost constant. And according to Table 5, all values of BMI-1 are less than 24.99, a threshold value which indicates that person is under normal category of health (according to BMI chart given in Table 1). Similarly, the value of c1, c2, c3 and c4 are also in the normal range category (though all are at their high end). Hence it may be concluded that person’s health is under normal category. But it seems impossible that increase in weight will not change any one of the values of c1, c2, c3 or c4. Anyone of these would definitely get changed. So if any of these (c1, c2, c3 or c4) is increased, it means person’s health is not under normal category of health.

Therefore, values of BMI-1 of Table 5 do not reflect correct status of the health. So we include the values of FC in the current formula of BMI-1 to get BMI-2. Table 6 provides values of BMI-1 and BMI-2 both.

Now according to Table 6, if BMI-1 is 23.88 and BMI-2 is 65.19 then that person is in normal category of health. But the moment weight increases, the value of c1, c2, c3 or c4 would also be changed. Now the person cannot be put under normal category of health. Therefore, for the present example, threshold value of BMI-2 is 65.19. If any one of c1, c2, c3 or c4 increases due to weight gain, the value of BMI-2 will also increase and may go beyond 65.19.

Table 5. Four Constants (FC) and BMI-1

| S. No. | c1 (cm) | c2 (cm) | c3 (cm) | c4 (cm) | FC=(c1+c2+c3+c4)/100 | Weight | Height (meter/m) | BMI-1 |
|--------|---------|---------|---------|---------|----------------------|--------|------------------|-------|
| 1      | 94      | 80      | 62      | 37      | 2.73                 | 80     | 6feet (1.83meter) | 23.88 |
| 2      | 94      | 80      | 62      | 37      | 2.73                 | 81     | 6feet (1.83meter) | 24.18 |
| 3      | 94      | 80      | 62      | 37      | 2.73                 | 82     | 6feet (1.83meter) | 24.47 |
| 4      | 94      | 80      | 62      | 37      | 2.73                 | 83     | 6feet (1.83meter) | 24.77 |
| 5      | 94      | 80      | 62      | 37      | 2.73                 | 83.5   | 6feet (1.83meter) | 24.92 |

Table 6. BMI-1 v/s BMI-2

| S. No. | c1 (cm) | c2 (cm) | c3 (cm) | c4 (cm) | FC=(c1+c2+c3+c4)/100 | Weight | Height (meter/m) | BMI-1 | BMI2=\((BMI1)^*(FC)\) |
|--------|---------|---------|---------|---------|----------------------|--------|------------------|-------|-----------------------|
| 1      | 94      | 80      | 62      | 37      | 2.73                 | 80     | 6feet (1.83meter) | 23.88 | 65.19 |
| 2      | 94      | 80      | 62      | 37      | 2.73                 | 81     | 6feet (1.83meter) | 24.18 | 66.01 |
| 3      | 94      | 80      | 62      | 37      | 2.73                 | 82     | 6feet (1.83meter) | 24.47 | 66.80 |
| 4      | 94      | 80      | 62      | 37      | 2.73                 | 83     | 6feet (1.83meter) | 24.77 | 67.62 |
| 5      | 94      | 80      | 62      | 37      | 2.73                 | 83.5   | 6feet (1.83meter) | 24.92 | 68.03 |
5. Conclusion

It may be concluded that along with BMI-1, it would be advisable to look into the BMI-2 values also, so as to get a more accurate picture of the health status.

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