Exploring The Relationship Between Body Mass Index and Body Fat Percentage Across Age and Gender: A Cross – Sectional Study

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KEYWORDS
Bioelectrical impedance analysis; body fat percentage; Body Mass Index; invisible obese; obesity.

ABSTRACT
Background: In today's fast-paced world, the prevalence of non- communicable diseases (NCDs) is rising due to work, academic and personal pressures. Obesity, a preventable disease, is often underestimated in clinical settings. The 'obesity paradox' where NCDs occur in individuals with normal body mass index (BMI), complicates health assessments. This study evaluates the relationship between BMI and body fat percentage (BFP) by age and gender and assesses if BMI alone is a good predictor of body adiposity. Methods: A cross-sectional observational study was conducted on 385 normal healthy subjects aged 18-67 years, attending an annual temple festival in Kerala during 2016. Subjects were selected based on the inclusion and exclusion criteria, after obtaining the ethical clearance. Using an Omron Body fat analyser, we measured BFP. Statistical analysis was done using Independent T test, ANOVA and Chi square test on SPSS version 20. Results: A significant increase in BMI and BFP with age in both genders, with BFP changes starting at a younger age. Females showed higher increases in both BMI and BFP. Among participants, 34% had normal BMI. 29% had normal BFP and only 20% had both normal. We also found many 'invisible' obese individuals within the normal BMI group and some 'muscle obese' individuals in the overweight BMI group. Conclusions: To conclude, as BMI and BFP increase with age, the quality of fat free mass likely deteriorates. BFP is a better predictor of adiposity compared to BMI. For early NCD detection, both BMI and BFP should be included in routine clinical screenings.

1. Introduction

Obesity has become a highly sought-after topic in contemporary research. Despite growing awareness of health risks, adult obesity has doubled since 1990 while adolescent obesity has quadrupled. The prevalence of obesity is so significant that as of 2022, 1 in 8 people worldwide were living with obesity. According to the World Health Organization, obesity is caused by an imbalance between energy intake and energy expenditure (1). There has been a documented upsurge in non-communicable diseases (NCDs) such as type 2 diabetes mellitus, coronary diseases, obstructive sleep apnoea and certain cancers (1,2). Rapid industrialization and subsequent urbanization have fostered a sedentary lifestyle, thereby increasing the incidence of NCDs.

Factors influencing body composition

Numerous studies have indicated that age, gender, genetic, behavioural and environmental factors influence age-related alterations in body composition (6,7). Among the Indian population aged between 15-49 years, the percentage of normal-weight individuals was less compared to overweight or obese individuals (from 19% to 23% among males and 21% to 24% among females) according to the National Family Health Survey (NFHS - 5, 2019 – 2021) (8). Men have increased lean mass compared to females. Research indicates that the decline in lean mass among females is more pronounced during peri-menopausal and younger years, while fat mass increases linearly with age in both genders (7). Generally, for a given BMI, females have a higher BFP than males. However, males have central adipose tissue distribution, while females have peripheral adipose tissue distribution. Hence, males have more negative metabolic consequences than females (9,10).

BMI and body composition analysis

BMI is a tool employed to assess an individual's general health status based on their weight and height. While it serves as a good indicator of chronic diseases, it is not a perfect measure as it does not directly assess body adiposity (11). To study body composition, several techniques are available such as tracer dilution, densitometry, dual-energy X-ray absorptiometry, air displacement plethysmography and bioelectrical impedance analysis (12,13). Because of the greater sensitivity and precision of fat-free mass and fat mass, magnetic resonance imaging (MRI) and computed tomography (CT) are considered the gold standard for body composition analysis (13). However, these techniques are very expensive, complicated and not feasible for large population studies. The bioelectrical impedance analysis (BIA) instrument is a cost effective and portable device that provides quick estimation of free-fat mass and lean mass in a population. As with any instrument, it has its advantages and disadvantages. Some studies have shown that BIA underestimates body fat at lower ranges and overestimates it at higher ranges when compared to results obtained from deuterium dilution (13). Despite its limitations, this instrument has been extensively used in numerous studies, particularly resource-limited and epidemiological research.

This study aims to contribute to the existing body of knowledge by providing scientific and specific data regarding the relationship between BMI and BFP in a South Indian population based on age and gender using BIA in a controlled environment as well as to estimate the number of invisible obese individuals from normal BMI individuals and to estimate the number of muscle obese individuals from high BMI individuals.

2. Materials and Methods

The study was conducted on 385 normal healthy subjects attending an annual temple festival in Kerala during 2016. This cross – sectional study included consenting males and females aged 18 to 67 years, selected based on specific inclusion and exclusion criteria and informed written consent was obtained. Exclusion criteria encompassed a history of metabolic diseases, surgeries and hospitalization (within 6 months), acute or chronic illness, menstruating females, pregnant and nursing mothers, any disabling conditions and lack of interest in participation. Institutional ethical approval (35/16/IEC/JMMC & RI) was obtained for the study.

Grouping and Measurements

The participants were categorized into 5 age groups: 18-27 years, 28-37 years, 38-47 years, 48-57 years and 58-67 years. Anthropometric measurements including height, weight and body composition were taken using appropriate instruments. Height was measured using a stadiometer (seca 206, Germany) in a standing position without footwear to the nearest 0.1cm. Weight and body composition were measured using a body fat analyser.

BMI was calculated using the standardized equation: weight (kg) divided by height (m2). The body fat analyser used in this study is a commercially available device named Omron – HBF-375 (Omron Healthcare, Japan - hand foot system). The device uses bioelectric impedance or resistance method by using weak current (50 KHZ, 500 µA) which provides reliable measurements of body composition that help categorize people based on their body fat or muscle mass. Previous studies have validated the reliability of this device for measuring the body composition. Since fluctuations in body water levels and situations such as after a large meal and exercising can alter body composition readings, the analysis was performed at 10am under controlled conditions (13).

Based in Asian standards (WHO), BMI was categorized as follows: < 18.5kg/m2 (underweight), 18.5-22.9 kg/m2 (normal), 23.0 – 24.9 kg/m2 (overweight), >/=25 kg/m2 (obese) (5). Body fat levels were categorised based on gender (male (M) / female (F)) provided by the device; ≥ 25% (M) /≥35% (F) – very high; 20-25% (M)/30-35% (F) – high; 10-20% (M)/20-30% (F)-normal; <10%(M)/< 20% (F) – low.

Statistical Analysis

Descriptive statistics were reported as mean and standard deviation (SD). A one-way Anova and an independent T test were used to compare BMI and BFP with age and gender. To understand the relationship between BMI and BFP, along with the estimation of the number of cases of invisible obesity and muscle obesity, chi square test was conducted. The data collected were analysed using SPSS software version 20. A p-value of <0.05 was considered significant and <0.01 was considered highly significant.

3. Results

In this study, 385 subjects were included, comprising 152 males (39.5%) and 233 females (60.5 %). The age distribution was as follows: 18-27 years (162 subject), 28-37 years (94 subjects), 38-47 years (63 subjects), 48-57 years (45 subjects) and 58-67 years (11 subjects). Table 1 outlines the anthropometric parameters utilized in this study, including age, height, weight, BMI and BFP.

According to BMI analysis, 14 female subjects (3.6%) and 7 male subjects (1.8%) were classified as underweight; 88 female subjects (22.9%) and 44 male subjects (11.4%) were classified as normal weight; 38 female subjects (9.9%) and 31 male subjects (8.1%) were classified as overweight and 93 female subjects (24.2%) and 70 male subjects (18.2%) were classified as obese. According to BFP analysis – 3 female subjects (0.8%) and 5 male subjects (1.3%) were classified in the low category; 76 female subjects (19.7%) and 37 male subjects (9.6%) were classified in the normal category; 80 female subjects (20.8%) and 38 male subjects (9.9%) were classified in the high category and 74 female subjects (9.1%) and 72 male subjects (18.7%) were classified in the very high category. Table 2 illustrates the variation in BFP and BMI with gender, indicating that BMI did not differ significantly between genders, whereas BFP was significantly higher among females than males.

As shown in table 3, there is a statistically significant increase in BFP and BMI with advancing age. However, the majority of obese men were observed to be in the age group of 28- 37 years and 38-47 years, whereas men in the very high category of BFP were predominantly in the age group of 28-37 years as shown in figure 1. Similarly, the majority of the obese females were observed to be in the age group of 28-37 years where as females in the very high category of BFP were predominantly in the age group of 18-27 years as shown in figure 2.

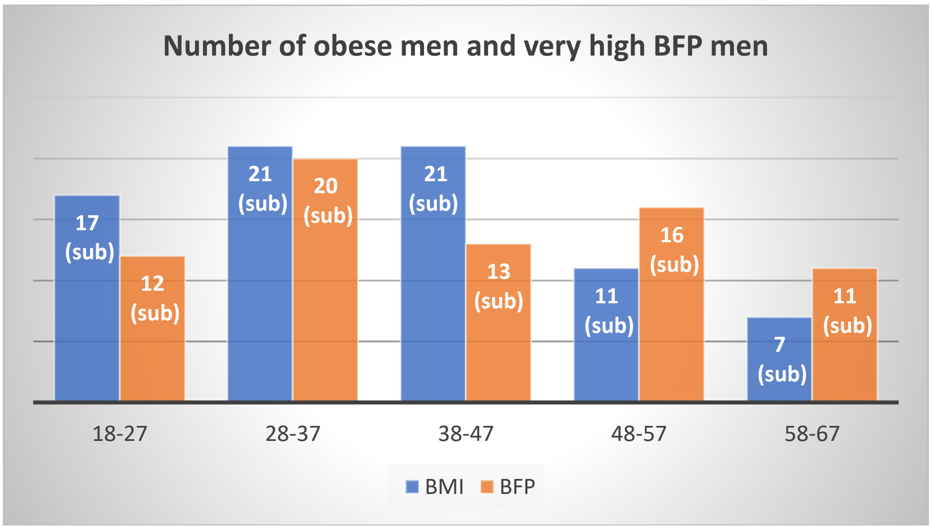

Figure 1: Graphical representation of the number of obese men and very high BFP men across age groups

BMI- Body Mass Index; BFP- Body Fat Percentage.The X axis shows the age group while the Y axis shows the number of male subjects in that category. The blue bar represents BMI while the yellow bar represents BFP.

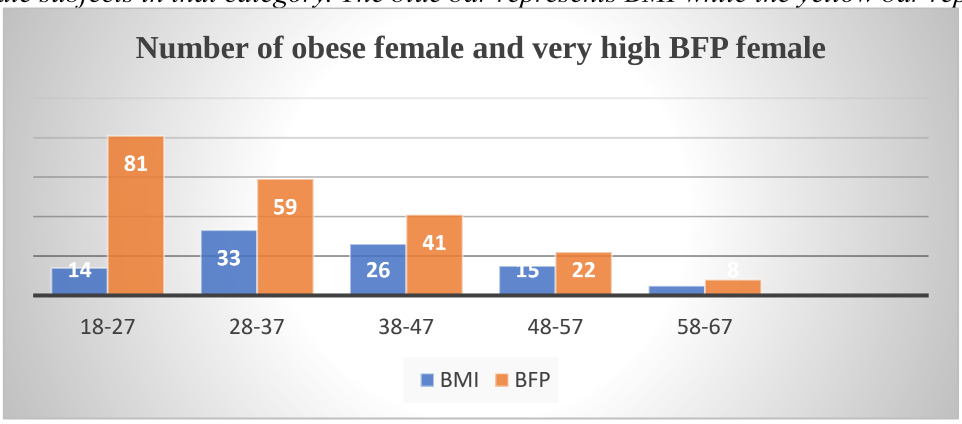

Figure 2: Graphical representation of the number of obese female and very high BFP female across

age groups.

BMI- Body Mass Index; BFP- Body Fat Percentage.The X axis shows the age group while the Y axis shows the number of female subjects in that category. The blue bar represents BMI while the yellow bar represents BFP.

Table 1: Demographic profile of the study group

Anthropometric parameters	N	Minimum	Maximum	Mean±SD
AGE	385	18.00	71.00	33.03±12.96
HEIGHT	385	1.61	187.00	161.4±12.21
WEIGHT	385	36.30	107.00	63.86±12.43
BMI	385	14.50	90.10	24.52±5.26
BFP	385	7.20	45.70	28.78±7.09

Values are mean±SD; BMI- Body Mass Index; BFP – Body Fat Percentage

Table 2: BFP and BMI variation with gender

Gender	n	BFP	BMI
Male	152	23.69±6.29	24.82±4.08
Female	233	32.1±5.44	24.32±5.90
p value		<0.001 **	0.361

Values are mean±SD; BMI – Body Mass Index; BFP – Body Fat Percentage. Comparison is made between BFP and BMI with gender (male and female) using Independent T test.
**p value <0.05 – significant*
***p value <0.01- highly significant*

Table 3: BFP and BMI variation in different age groups

Age intervals	n	BFP	BMI
18-27	162	25.33±6.73	22.35±3.62
28-37	94	30.36±5.96	25.58±3.45
38-47	63	31.69±6.36	26.60±9.00
48-57	45	32.56±6.56	26.59±4.18
58-67	21	31.51±6.47	25.75±3.47
Total	385	28.78±7.09	24.52±5.26
p value		<0.001**	<0.001**

Values are mean±SD; BMI – Body Mass Index; BFP – Body Fat Percentage. Comparison is made between BMI and BFP among various age groups using One – way ANOVA.
**p value <0.05 – significant*
***p value <0.01- highly significant*

Table 4: Distribution of BFP among genders in different age groups

Age Intervals (years)	Males (n=152)	BFP (males) Mean±SD	Females (n=233)	BFP (females) Mean±SD	P vlaue
18 – 27	60	19.9±6.5	102	28.5±4.4	<0.001**
28-37	35	25.0±5.1	59	33.5±3.7	<0.001**
38-47	21	26.0±4.0	42	34.5±5.3	<0.001**
48-57	23	27.5±4.7	22	37.9±3.1	<0.001**
58-67	13	27.4±4.1	8	38.2±3.0	<0.001**
P value		<0.001**		<0.001**	

Values are mean±SD; BFP – Body Fat Percentage; BMI – Body Mass Index. Compares BFP between males and females across different age groups using Independent T test
**P value <0.05 – significant*
***p value <0.01 – highly significant*

Table 5: Distribution of BMI among genders in different age groups

Age Intervals (years)	Males (n=152)	BMI (males) Mean ±SD	Females (n=233)	BMI (females) mean±SD	P vlaue
18-27	60	23.5±4.3	102	21.7±3.0	0.003**
28-37	35	25.5±3.0	59	25.6 ±3.7	0.898

38-47	21	25.4±3.8	42	27.2 ±10.7	0.477
48-57	23	26.5±4.9	22	26.7 ±3.4	0.864
58-67	13	25.3±2.7	8	26.5 ±4.6	0.434
P value		0.014**		<0.001**	

Values are mean±SD; BFP – Body Fat Percentage; BMI – Body Mass Index. Compares BMI between males and females across different age groups using Independent T test
**P value <0.05 – significant*
***p value <0.01 – highly significant*

Table 6: Association of BFP with BMI

BODY COMPOSITION		**BMI**				**Total**	**p Value**
		Under weight (<18.5)	**Normal (18.5-22.9)**	**Over weight (23-24.9)**	**Obese (>=25)**		
BFP	**LOW**	5 (23.8%)	2 (1.5%)	0 (0.0%)	1 (0.6%)	8 (2.1%)	<0.001**
	NORMAL	14 (66.7%)	79 (59.8%)	18 (26.1%)	2 (1.2%)	113 (29.4%)	
	HIGH	1 (4.8%)	39 (29.5%)	35 (50.7%)	43 (26.4%)	118 (30.6%)	
	V.HIGH	1 (4.8%)	12 (9.1%)	16 (23.2%)	117 (71.8%)	146 (37.9%)	
TOTAL		21 (100.0%)	132 (100.0%)	69 (100.0%)	163 (100.0%)	385 (100.0%)	

Values are mean±SD; BFP – Body Fat Percentage; BMI – Body Mass Index. Compares the association between BFP and BMI using Chi Square test
**P value <0.05 – significant*
***p value <0.01 – highly significant*

Table 4 demonstrates a statistically significant increase in BFP in both genders with advancing age whereas table 5 shows a statistically significant increase in BMI with advancing age in both the genders, with a more pronounced increase among females.

Table 6 describes the association between BMI and BFP in the study group. Of 385 participants, only 79 was found to be within the normal limits. When BMI alone was considered, 132 participants were found to be normal while considering BFP alone, 113 participants were found to be normal.

4. Discussion

The contemporary stressful lifestyle combined with a lack of time and the adoption of unhealthy dietary patterns, has compelled individuals to become sedentary. This sedentary lifestyle has resulted in an imbalance between fat and muscle ratio, leading to the development of a new man-made syndrome of this era, which is a major contributor to the increasing incidence of obesity. High adiposity coexists with muscle loss, which in turn affects the normal body functions and significantly impacts the incidence of NCDs in the present generation. To achieve metabolic homeostasis, maintaining of optimal body adiposity should be the primary goal. Therefore, this study was designed to investigate the relationship of BMI and BFP with age and gender in the South Indian Population as well as to explore the existence of invisible obesity (normal weight obesity) and muscle obesity (increased weight obesity) within the population.

Table 2 shows that both genders have same BMI but women have higher BFP, which was found to be statistically significant and has been reported in previous studies (2,7,14) According to Robergs and Roberts (1997), a healthy range of body fat for women is 20-25% and for men, it is 10-15% (15). However, the distribution of body fat differs between genders. Fat accumulation in females is typically around the hip and thighs (gynaecoid or pear body type) while males generally develop abdominal obesity (android or apple body type). Individuals with an android body pattern, characterized by central obesity (visceral obesity), have an increased risk of developing metabolic complications compared to those with peripheral or gynaecoid body pattern (16,17). However, menopause females may develop an android type of fat distribution as highlighted by Wells JC (18). The distribution of fat in the body is mainly influenced by hormones such as testosterone and oestrogen. Consequently, men tend to have more muscle and bone mass while women develop more body fat for reproductive functions and hormone regulation (2,7).

Table 3 demonstrates that both BFP and BMI increase with age, with the change being more pronounced in BFP. As age progresses, there is a redistribution of adipose storage sites from subcutaneous fat depots to more harmful ectopic sites like in the visceral sites (19). Variations in body composition due to age related changes are attributed to physical inactivity, menopausal status, nutritional status and disease occurrence (20). The increase in fat mass and decrease in lean mass with age suggest a reduction in resting energy expenditure (REE) and decreased macronutrient oxidation rate (7). Additionally, we observed that in elderly subjects, BMI decreases and BFP increases, a finding consistent with another study (14). This phenomenon can be reasonably explained by the progressive loss of muscle mass and body fat accumulation due to prolonged physical inactivity, motor – unit remodelling, decreased hormone levels and decreased protein synthesis associated with aging (14).

Table 4 and table 5 show that both BFP and BMI increase with age in both males and females. In all age groups, the mean BFP was higher in females than in males as reported by other studies (2,14). A statistically significant difference in BFP was observed between males and females in each age interval. However, except for the age interval of 18-27 years, no statistically significant difference in BMI was found between the genders in other age groups. Another notable finding from this study is that in the age group of 18-27 years, both males and females are at the upper limit of normal fat distribution. When comparing BMI, males were found to have higher BMI than females. This indicates that individuals in this prime age group are already at risk of obesity, likely due to poor lifestyle choices. This finding was also observed in the study by Misra P et al study (10).

Although the distribution of subjects in each age group was unequal, we observed that obese males with very high BFP were predominantly in the age group of 28-37 years and 38-47 years. In contrast, obese females were mainly in the age group of 28-37 years but females with very high BFP were largely seen in the 18-27 age group, as shown in figure 1 and 2 respectively. These findings contradict those of Sarvottam et al, who observed low BMI, waist circumference and BFP in the age group 18 – 29 years in both genders.

We assumed that the current generation especially in the age group of 18-27 years, would exhibit increased fitness awareness and health consciousness, but this assumption appears to be incorrect which is highly alarming. This change may be is attributed to the fast-paced and stressful lifestyle. The alarming increase in BMI is known to induce stress, affect blood pressure and health related quality of life in young adolescents (21,22,23).

Another important observation is that the transition from normal to abnormal levels of BFP occurs around the age group of 28-37 years, which was also noted in another study (7).

Table 9a describes the association between BMI and BFP in the study group. Considering both BMI and BFP, only 79 out of 385 participants were found to be within normal limits. When BMI alone was considered, 132 participants were found to be normal whereas considering BFP alone, 113 participants were found to be normal. This clearly points towards the fact that neither BMI nor BFP alone can be considered reliable indicators of health status. Among 132 participants with normal BMI, 39 subjects had high BFP and 12 subjects had very high BFP. This shows that obesity in these individuals is not apparent if only BMI was taken into account. The type of obesity in these individuals is known as invisible obesity. This group that is often neglected due to their lower BMI values, making them susceptible to health deterioration leading to NCD in the near future (24). Of the 69 subjects belonging in the overweight category, 18 had normal BFP indicating their weight was primarily due to muscles rather than fat and they are physiologically healthy. These individuals are often mislabelled and criticized for their body appearance and weight and are often pressurised exercise. However, the reality is that these individuals are healthy and a high BMI need not be a cause for concern. Similar results were observed in several studies suggesting that an elevated BMI does not necessarily represent poor health status (25,26). Several newer terminologies have been introduced such as metabolically healthy obese (MHO), metabolically abnormal obese (MAO), metabolically obese normal weight (MONW) and sarcopenic obesity. In MHO, individuals have excess body fat but lack metabolically adverse profiles such as insulin resistance, glucose intolerance, type 2 diabetes and cardiovascular disease. However, these individuals can transition from metabolically healthy overweight/ obese to metabolically abnormal overweight/ obese. In MAO, individuals have excess body fat with metabolic syndrome and other NCDs. In MONW, individuals are metabolically abnormal with normal BMI, also known as pre-obese individuals. (27). Lastly, sarcopenic obesity refers to individuals with reduced muscle mass and strength and increased body fat (17). These obesity subgroups require further investigation to gain a deeper understanding of the relationship of body fat with health status.

The findings of the present study provide a fundamental understanding of the relationship between BMI and BFP with age and gender. The study also highlights that the female population is at a higher risk for NCDs across all age group compared to males. However, the increase in body fat begins from a younger age group and continues into older age group, irrespective of the gender. The significance of BFP as a parameter in the assessment of obesity is also emphasized. While measuring BFP using BIA may not be a reliable in comparison to sophisticated methods like Dual – Energy X-ray or MRI, but it can serve as a potential clinical tool for large population surveys, saving time and money. It is a convenient method for use in community-based rural settings, as it does not require specialized skills or knowledge to operate the device (28). Every clinician should be made aware of the limitations of BMI as a measure of obesity and should also consider BFP to assess and predict the health status of an individual.

Modern day medicine has increased the life span. But longevity should be associated with a high quality and disability free life. BMI classification showed 42% of the study population are obese while 17% are overweight and 34% are normal. BFP classification shows that only 29% of the study population are normal while the rest have high to very high body fat. Hence BFP classification picks out those overweight individuals which were missed out in the BMI classification. 13% of this population which was missed out by BMI classification have high BFP causing invisible obesity: of these 10% are men and 15% are women while 5% both men and women had muscular obesity contributing to the high BMI. This study accentuates that BMI by itself is not a holistic indicator, but when combined with BFP becomes an ideal predictor of development of adiposity and further development of NCDs.

5. Limitation

Being cross sectional study, the understanding of the development and progression of deleterious effect of obesity is limited. For this study, although we have endeavoured to maintain a controlled environment based on the prerequisites for BIA measurement, the information provided by the subjects may vary, potentially affecting the study sensitivity. While the accuracy of BIA is questionable compared to various complex devices or multicomponent models for measurement of body composition, BIA remains a suitable tool for epidemiological studies involving large populations. It is also recognized for its simplicity, acceptability and rapid data acquisition (28). In this study, we have measured total body fat rather than fat in specific areas such as the liver where certain studies have suggested that excess fat in hepatocytes contributes more to the development of metabolic syndrome than visceral fat [29]. Further research is necessary to address the gaps in this area of interest. Additionally, more studies are required to investigate the impact of increased BFP on disability.

6. Perspectives and Significance

The study highlights females are at a higher risk for NCDs across all age groups compared to males, emphasizing the need for targeted public health interventions. The increase in body fat starts from a young age and continues into older age, indicating the importance of early intervention and continuous monitoring to prevent obesity related complications. The study underscores the significance of BFP as a crucial parameter in assessing obesity, suggesting that clinicians should consider BFP alongside BMI for a more accurate evaluation of an individual’s health status. For ensuring a more holistic approach to obesity management, clinicians should be aware of the limitations of BMI and incorporate BFP measurements for better assessment and prediction of health outcomes.

References

[1] World Health Organization. Obesity and overweight [Internet]. World Health Organization. 2024. Available from:

[2] http://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

[3] Rai R, Ghosh T, Jangra S, et al. Relationship Between Body Mass Index and Body Fat Percentage in a group of Indian Participants: A Cross- Sectional Study From a Tertiary Care Hospital. Cureus. 2023 Oct;15(10):1-8.

[4] Gupta SRN. Body Composition Analysis of Staff members of College Using Bioelectrical Impedance Analysis Method. International Journal of Chemical Engineering and Applications. 2014 Jun;5(3):259-65.

[5] Sandeep KS, Singaraju GS, Reddy VK, Mandava P, Bhavikati VN, Reddy R. Evaluation of body weight, body mass index, and body fat percentage changes in early stages of fixed orthodontic therapy. J Int Soc Prev Community Dent. 2016 Jul-Aug;6(4):349-58.

[6] WHO Regional Report (2000) The Asian – Pacific perspective redefining obesity and its treatment, Health Communications Australia Pvt Limited, Australia. [cited 2018 June 12] Available from: www.wpro.who.int/nutrition/documents/docs/redefiningobesity.pdf.

[7] Macek P, Terek – Derszniak M, Biskup M, Krol H, Smok-Kalwat J, Gozdz S, Zak M. Assessment of Age- Induced Changes in Body Fat Percentage and BMI Aided by Bayesian Modelling: A Cross- Sectional Cohort Study in Middle – Aged and Older Adults. Clin Interv Aging. 2020 Dec 8;15:2301-2311.

[8] Sarvottam K, Ranjan P, Yadav U. Age group and gender – wise comparison of obesity indices in subjects of Varanasi. Indian J Physiol Pharmacol. 2020;64(2):109-17.

[9] Shekar M, Popkin B: Obesity: Health and Economic Consequences of an Impending Global Challenge. World Bank Publications, Washington, DC; 2020.

[10] Muscogiuri G, Verde L, Vetrani C, Barrea L, Savastano S, Colao A. Obesity: a gender-view. Journal of Endocrinological investigation. 2023 Sep 23;47:299-306.

[11] Misra P, Singh AK, Archana S, Lohiya A, Kant S. Relationship between body mass index and percentage of body fat, estimated by bio-electrical impedance among adult females in a rural community of North India: A cross-sectional study. J Postgrad Med. 2019 Jul-Sep;65(3):134-140.

[12] Khanna D, Peltzer C, Kahar P, Parmar MS. Body Mass Index (BMI): a Screening Tool Analysis. Cureus [Internet]. 2022 Feb 11;14(2). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8920809

[13] De Lorenzo A, Soldati L, Sarlo F, Calvani M, Di Lorenzo N, Di Renzo L. New obesity classification criteria as a tool for bariatric surgery indication. World J Gastroenterol. 2016 Jan 14;22(2):681-703.

[14] Kuriyan R. Body Composition Techniques. Indian J Med Res. 2018;148(5):648-658.

[15] Ranasinghe C, Gamage P, Katulanda P, Andraweera N et al. Relationship between Body mass index (BMI) and body fat percentage, estimated by bioelectrical impedance, in a group of Sri Lankan adults: a cross sectional study. BMC public Health.2013;13:797.

[16] Robergs RA, Roberts SO. Exercise physiology: exercise and clinical applications. St Louis: Mosby;199.546-563.

[17] Johnston FE, Wadden TA, Stunkard AJ, Pena M et al. Body fat deposition in adult obese women. I patterns of fat distribution. Am J Clin Nutr. 1988;47:225-8.

[18] Mayoral LPC, Andrade GM, Mayoral EPC, Huerta TH et al. Obesity subtypes, related biomarkers and heterogeneity. Indian J Med Res. 2020;151(1):11.

[19] Wells JC. Sexual dimorphism of body composition. Best Pract Res Clin Endocrinol Metab. 2007;21:415-30.

[20] Addison O, Marcus RL, LaStayo PC, Ryan AS. Intermuscular Fat: A Review of the Consequences and Causes. International Journal of Endocrinology. 2014;1-11.

[21] Silva Nde A, Pedraza DF, de Menezes TN. Physical performance and its association with anthropometric and body composition variables in the elderly. Cien Saude Colet. 2015;20(12):3723-32.

[22] Archana Rajagopalan, Nisha Balaji. Association of neck circumference and obesity with blood pressure among adolescents in urban and rural population in North Tamil Nadu. JNSBM. 2017;8(2):144-149.

[23] Dharshini K, Thaneema Nasreen, Archana R. A cross sectional study on health related stress amongunderweight,obese and overweight undergraduate medical students. IJRAP. 2017;8(2):230-233.

[24] Nivetha Kumari , Mokana L, Archana R . A cross sectional study on health related quality of life among underweight, obese and overweight undergraduate medical students. IJRAP.2017;8(2):248-251

[25] Gebremedhin S, Mekonene M, Hagos S, Baye K, Shikur B, Berhane A et al. Association between normal-weight obesity and cardiometabolic risk factors among adults in Addis Ababa, Ethiopia. Scientific Reports [internet]. 2023;13(1):22772.

[26] Etchison WC, Bloodgood EA, Minton CP, Thompson NJ et al. Body Mass Index and Percentage of Body Fat as Indicators for Obesity in an adolescent Athletic Population. Sports Health. 2011;3(3):249-52.

[27] Witt KA, Bush EA. College athletes with an elevated body mass index often have a higher upper arm muscle area, but not elevated triceps and subscapular skinfolds. J Am Diet Assoc. 2005;105(4):599-602.

[28] Thomas EL, Frost G, Taylor-Robinson SD, Bell JD. Excess body fat in obese and normal-weight subjects. Nutrition Research Reviews. 2012;25(1):150-61.

[29] Meeuwsen S, Horgan GW, Elia M. The relationship between BMI and percent body fat, measured by bioelectrical impedance, in a large adult sample is curvilinear and influenced by age and sex. Clin Nutr.2010;29(5):560-566.

[30] Stefan N, Kantartzis K, Machann J, Schick F, Thamer C, Rittig K et al. Identification and characterization of metabolically benign obesity in humans. Arch Intern Med. 2008 Aug 11;168(15):1609-16.