Age, Diabetes and Nutrient Intake Influence the Risk of Obese and Non-obese Sarcopenia in Individuals aged over 40 years in Urban Bengaluru, India

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Abstract

In India, obesity has been a growing concern. The coexistence of obesity and sarcopenia can have serious health implications. We aimed to assess the prevalence of sarcopenia and identify the factors influencing it in obese and non-obese individuals using the South Asian guidelines (SWAG-SARCO). We selected 603 adults aged between 40 to 80 years residing in urban Bengaluru. We measured their weight, height, waist circumference, calf circumference and hand grip strength. We also used short physical performance battery and 24-hour recall to study their muscle function and nutrient intake respectively. We used multinominal regression analysis to identify the predictors of sarcopenia. Thirty-one per cent of the participants had sarcopenia. The prevalence of sarcopenic obesity and non-obese sarcopenia was 20.6% and 10.2% respectively. Multinominal regression analysis indicated that age, diabetes, higher energy intake increased the odds of having sarcopenia in both obese and non-obese groups (p < 0.05). Dietary protein intake was seen to offer protection against sarcopenia in both obese and non-obese groups (p < 0.05). Individuals with family history of arthritis had increased odds of sarcopenia in obese individuals (p < 0.05). On the other hand, dietary calcium and fat intake were protective against sarcopenia in obese and non-obese individuals respectively (p < 0.05). Sarcopenia was seen to be more prevalent in the obese. South Asian guidelines allowed more effective identification of sarcopenia with the use of practical, economical and reliable tools. Efforts need to be made to include screening for sarcopenia in regular clinical assessment to aid in prevention and treatment of sarcopenia.

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Abbreviations

IHEC	Institutional Human Ethical Committee
SWAG-SARCO	South Asian Working Group on Sarcopenia
AWGS	Asian Working Group on Sarcopenia
SES	socioeconomic status
BMI	body mass index
SPPB	short physical performance battery
UW	underweight
OW	overweight

Introduction

Sarcopenia has been considered as a geriatric syndrome. Over the past decade the focus on sarcopenia has grown. Evidence suggests that the decline in muscle mass begins from as early as 30 years. Post the age of 30, muscle mass is said to decline at a rate of 0.5 to 1.0% per year.[1] Consequently, the muscle strength has also been observed to decline by 20 to 40% between 30 to 80 years.[1] Poor muscle mass and muscle strength can potentially adversely impact muscle function or performance. The South Asian consensus suggests the presence of any two of the following – low muscle mass, low muscle strength or low muscle function for the diagnosis of sarcopenia.[2] The prevalence of sarcopenia in non-institutionalized older adults using the Asian and European guidelines ranged between 9.9 – 40.4%.[3,4]

Alongside the decline in the muscle mass, ageing is marked by an increase in the body fat. Obesity or adiposity is considered to be an inflammatory state. Reports indicate that this inflammation may induce decline in the muscle protein synthesis leading to reduced muscle strength.[5,6] This gives rise to the coexistence of sarcopenia with adiposity which has been termed as sarcopenic obesity. Other factors that may predispose individuals with obesity to sarcopenia are increased intramuscular fat, low physical activity, limited functional capacity and comorbid conditions such as metabolic syndrome. Evidence suggests that sarcopenic obesity has been associated with comorbid conditions such as diabetes, hypertension, cardiovascular diseases, impaired activities of daily living and instrumental activities of daily living.[7–12] Further, sarcopenic obesity increased the risk of mortality.[13,14]

In India, obesity is emerging as a health crisis. Studies also support that prevalence of obesity/ adiposity has considerably risen. In 2015, the ICMR-INDIAB study found that the prevalence of obesity ranged from 11.8 to 31.3% while abdominal obesity ranged from 16.9 to 36.3% in four Indian states.[15] In another nationwide survey, nearly 40% of the men and women were found to be obese.[16] The latest National Family and Health Survey (2019-21) found 40% women and 12% men had abdominal obesity. The survey also pointed that abdominal obesity was likely to be more prevalent among women, older age groups, higher socioeconomic groups and urban residents.[17] By 2040, it has been predicted that the prevalence of overweight/obesity would increase by five times in urban areas.[18]

The rising levels of obesity combined with other risk factors such as sedentary lifestyle and nutrition transition can potentially increase the risk of sarcopenia in the Indian population. The presence of sarcopenia, obesity along with the non-communicable diseases can potentially elevate the disease burden and impact our productivity as well as quality of life. Few Indian studies have focussed on sarcopenia and sarcopenic obesity.[15,19–23] These studies have primarily concentrated on older adults and have used either the European or the Asian consensus for identifying sarcopenia. Asian Working Group on Sarcopenia (AWGS) emphasized heavily on presence of low muscle mass for the diagnosis of sarcopenia. In 2022, the South Asian consensus statement for diagnosis of sarcopenia was published.[2] Unlike the European or Asian guidelines, South Asian consensus emphasizes equally on muscle mass, muscle strength and muscle function. As per the consensus, loss of each of these parameters has been associated with adverse health outcomes. Use of the South Asian guidelines may aid in identifying sarcopenia cases that would have been missed with the use of the widely used AWGS criteria.

Considering the early effect of ageing on muscles along with the sedentary lifestyle and the rampant obesity in our population, we aimed to study the prevalence of sarcopenic obesity (using the South Asian guidelines) and the factors influencing it in urban population.

Materials and Methods
Study Design – Cross Sectional Design
Ethical approval
The study was approved by the Institutional Human Ethical Committee (IHEC), Mount Carmel College, Autonomous Bengaluru. (IHEC-MCC No. 018 M.Sc./2021-22).

Study Participants
We selected 603 community-dwelling adult participants aged 40 – 80 years from Bengaluru city using cluster sampling. The sample size was estimated based on the formula – $n = [Z^2P (1 – P)]/d^2$ with a prevalence of 6% with a precision of 2%.[3,4] Based on the electoral constituencies, we divided Bengaluru, urban in to three zones – south, north and central. We selected two clusters – north and central. Within these clusters, we selected four localities each. To recruit participants for this study, we approached housing societies, apartments and residential colonies in all the eight localities from the two clusters. Permission was taken from the managers of these societies or apartments and a message was either displayed or sent by the welfare association to the residents of the apartments informing them about the study. The participants were provided written information about the study and were included in the study after obtaining written informed consent. We excluded the following individuals -

• Those with muscle or bone related issues and diseases myopathy, neuropathy, physical disabilities or had fractures in the last three months.
• Those who were bed-ridden or wheel-chair bound.
• Those who were suffering from Parkinson's disease or Alzheimer's disease or dementia.

Measurements
Anthropometric measurements like height, weight and waist circumference were measured in triplicates.[24] We assessed the presence of sarcopenia using the South Asian Working Group on Sarcopenia (SWAG-SARCO) guidelines.[2] We used calf circumference as an indicator of muscle mass. Calf circumference is confounded by the effect of BMI. To eliminate the effect of adiposity, we adjusted the calf circumference for BMI.[25] Further, we used SWAG-SARCO recommendations for calf circumference < 34 cm for men and < 33 cm for women for screening or case-finding. Muscle strength was measured using Saehan digital handheld dynamometer (DHD-1, 0501-003). According to SWAG-SARCO guidelines, cut offs of <27.5 kg for men and <18.0 kg for women were recommended to identify individuals with 'possible sarcopenia'. Short physical performance battery (SPPB) was used to measure muscle function. It measures walking speed, standing balance, and sit-to-stand performance. The Asian Working Group on Sarcopenia (AWGS) recommends a cut-off of ≤ 9 as low physical performance.[7] According to SWAG-SARCO, presence of any two parameters confirms the diagnosis of sarcopenia - low muscle mass, low muscle strength and low muscle function.[2]

Based on the presence of sarcopenia and Asian BMI cut-offs, we classified individuals in the following groups – sarcopenic underweight (UW) (< 18.5 kg/m²), sarcopenic normal BMI (18.5 – 22.9 kg/m²), sarcopenic overweight (23.0 – 24.9 kg/m²), sarcopenic obese (> 25.0 kg/m²) and no sarcopenia.[2,26]

Assessment of Dietary Intake
We used 24-hour diet recall to assess the dietary intake of the participants. Participants were asked to describe any food or beverage they consumed in the last 24-hours in terms of the quantity consumed, the ingredients used along with the time it was consumed. To estimate the portion of food consumed, standard measuring cups and spoons were used. Nutrient intake per day was calculated using NutriCal (NSR NutriCal version 3.1).

Other Variables
General information like the participant's age, gender, physical activity type and duration, family history of diseases and if the participant suffers from any diseases was collected in a personal interview. The socioeconomic status (SES) of the participants was assessed using the Modified Kuppuswamy socioeconomic scale updated for the year 2021.[27]

Statistical Analysis

Data were analyzed using IBM SPSS 20.0. Mean ± SD and frequency distribution were done for continuous and categorical variables respectively. To find out the independent variables predicting the risk of non-obese sarcopenia and sarcopenic obesity, we carried out multinominal regression analysis. In the regression model, we considered – age, sex, family medical history, comorbidities, energy (kcals/d), protein (g/d), carbohydrates (g/d), fat (g/d), calcium (mg/d) and iron (mg/d) as the independent variables.

Results

Overall, 30.8% (n= 186) participants had sarcopenia. We found 16.8% (n = 101) and 3.8% (n = 23) participants to have sarcopenic obesity and sarcopenic overweight respectively. On the other hand, 1.3% (n = 8) and 8.9% (n = 54) participants were seen to have sarcopenia with underweight and sarcopenia with normal BMI. For the purpose of the analysis, we clubbed the sarcopenic obesity and sarcopenic overweight groups together. Likewise, we combined sarcopenia with underweight and sarcopenia with normal BMI together.

Table 1 presents the differences in their age, SES, sarcopenic variables and dietary intake. The sarcopenic obese group were significantly older than the individuals without sarcopenia but younger than those with non-obese sarcopenia (p < 0.0001). After adjusting the calf circumference for BMI, the mean calf circumference of the sarcopenic obese group did not differ from the individuals without sarcopenia. However, individuals with non-obese sarcopenia had significantly lower calf circumference than those with sarcopenic obesity (p < 0.0001). The individuals with sarcopenic obesity reported significantly lower protein and fat consumption as compared to those with non-obese sarcopenia (p < 0.05).

Table 1: Mean ± SD Age, SES, Anthropometry and Dietary Intake of the Participants

Variables	No Sarcopenia (n = 417)	Non-obese Sarcopenia (n = 62)	Sarcopenic OW/Obese (n = 124)	F	p
Age (years)	52.77 ± 9.9[a]	64.45 ± 11.2[b]	58.77 ± 12.5[c]	41.300	<0.0001
SES score	14.82 ± 6.1[abc]	13.74 ± 5.4[ab]	16.07 ± 6.0[abc]	3.442	0.033
BMI (kg/m^2)	25.27 ± 4.5[a]	20.40 ± 1.9[b]	27.5 ± 2.8[c]	66.278	<0.0001
Waist circumference (cm)	91.88 ± 10.2[a]	89.48 ± 10.9[ab]	96.04 ± 8.8[ac]	11.240	<0.0001
Calf circumference (cm)	34.0 ± 4.0[a]	31.25 ± 3.2[b]	33.53 ± 3.4[a]	13.933	<0.0001
Hand grip strength (kg)	30.89 ± 10.6[a]	17.85 ± 6.3[b]	19.76 ± 6.7[bc]	97.991	<0.0001
SPPB score	13.97 ± 2.3[a]	10.13 ± 4.1[b]	11.43 ± 3.6[c]	76.299	<0.0001
SARC-F	0.57 ± 1.1[a]	1.88 ± 2.0[b]	1.46 ± 1.7[bc]	37.566	< 0.0001
Energy (kcals/d)	1485.39 ± 384.2	1591.30 ± 356.9	1521.55 ± 396.1	2.222	0.109
Protein (g/d)	38.09 ± 9.1[ab]	37.02 ± 8.0[ab]	35.06 ± 9.4[bc]	5.453	0.004
Carbohydrates (g/d)	165.23 ± 50.8	162.80 ± 46.2	158.75 ± 44.2	0.843	0.431
Fat (g/d)	61.63 ± 32.0[ab]	72.84 ± 34.2[b]	60.02 ± 32.9[ac]	3.661	0.026
Calcium (mg/d)	657.03 ± 209.5	662.30 ± 193.5	631.1 ± 200.5	0.840	0.432
Iron (mg/d)	10.0 ± 3.5	9.71 ± 2.5	9.82 ± 3.03	0.306	0.736

Values with different superscript differ significantly. SES – socioeconomic status, BMI – body mass index, SPPB – short physical performance battery, OW – overweight.

Table 2 depicts that greater proportion of men had sarcopenic obesity than women (χ2 = 11.387, p = 0.003). Absence of family history was reported by 25% and 50% of the participants in the obese sarcopenia and non-obese sarcopenia group respectively (χ2 = 34.450, p < 0.0001). Further, higher proportion of participants from sarcopenic overweight/obese group had a family history of arthritis (27.4%) and diabetes (30.6%) than the other groups (p < 0.0001). Almost 60% of the participants in the no sarcopenia group did not suffer from any comorbid conditions (χ2 = 19.968,

p = 0.010). Sixty-six per cent of the individuals with non-obese sarcopenia and 58% in the sarcopenic overweight/obese group were seen to suffer from either one of the comorbid conditions as compared to the other groups (p < 0.0001). The most commonly reported conditions among them were diabetes and hypertension/CVD. Interestingly, more individuals in the non-obese sarcopenia group reported having diabetes than the other groups (p < 0.0001).

Table 2: Distribution of Participants based on Sex, Exercise, Family History and Comorbidities

Variables	No Sarcopenia (n = 417)	Non-obese Sarcopenia (n = 62)	Sarcopenic overweight/obese (n = 124)	χ^2	p
Sex: Male	47.0 (196)	45.2 (28)	63.7 (79)	11.387	0.003
Female	53.0 (221)	54.8 (34)	36.3 (45)		
Exercise: Yes	46.0 (192)	56.5 (35)	52.4 (65)	3.339	0.118
No	54.0 (225)	43.5 (27)	47.6 (59)		
Family history					
Arthritis	11.0 (46)	17.7 (11)	27.4 (34)	34.450	<0.0001
HTN/CVD	16.5 (69)	6.5 (4)	13.7 (17)		
Diabetes	24.2 (101)	24.2 (15)	30.6 (38)		
Other	2.2 (9)	1.6 (1)	3.2 (4)		
None	46.0 (192)	50.0 (31)	25.0 (31)		
Comorbidities					
Arthritis	16.5 (69)	8.1 (5)	14.5 (18)	49.030	<0.0001
HTN/CVD	11.0 (46)	24.2 (15)	21.0 (26)		
Diabetes	7.7 (32)	29.0 (18)	17.7 (22)		
Other	5.5 (23)	4.8 (3)	4.8 (6)		
None	59.2 (247)	33.9 (21)	41.9 (52)		

CVD/HTN – cardiovascular disease/hypertension, OW - overweight

As seen in Table 3, age, female gender and diabetes were seen to increase the odds of non-obese sarcopenia (p < 0.05). Among the other independent variables, daily energy intake influenced the presence of non-obese sarcopenia (OR – 1.003, 95% CI: 1.002– 1.005; p < 0.0001). On the other hand, higher daily protein (OR – 0.938, 95% CI: 0.893 – 0.986; p = 0.012) and fat intake (OR – 0.979, 95% CI: 0.963 – 0.995; p = 0.011) were seen to be protective against the presence of non-obese sarcopenia.

As in the earlier case, age, family history (arthritis and diabetes), diabetes and higher energy intake increased the odds of developing sarcopenic obesity (p < 0.05). Higher protein (OR – 0.921, 95% CI: 0.887 – 0.956; p < 0.0001) and calcium intake (OR – 0.998, 95% CI: 0.997 – 1.000; p = 0.005) were seen to offer protection against sarcopenic obesity.

Discussion
We found that one-third of the participants had sarcopenia. Overall, 20.6% participants had sarcopenia along with overweight/obesity. On the other hand, 10.2% participants had low or normal BMI with sarcopenia i.e. non-obese sarcopenia. Older age, comorbid conditions such as diabetes, higher energy intake were seen to increase the odds of having sarcopenia irrespective of the BMI of the participants. Higher dietary protein intake was seen to offer protection against sarcopenia across the BMI categories.

Table 3: Multinominal analysis of factors influencing non-obese sarcopenia and sarcopenic obesity

Variables	Non-obese Sarcopenia			Sarcopenic OW/Obese		
	B (SE)	OR (95% CI)	P	B (SE)	OR (95% CI)	P
Age (years)	0.108 (0.018)	1.115 (1.075 – 1.155)	< 0.0001	0.055 (0.14)	1.056 (1.029 – 1.085)	< 0.0001
Sex (Female)	0.868 (0.363)	2.381 (1.170 – 4.848)	0.017	-0.372 (0.299)	0.689 (0.384 – 1.238)	0.213
Family History						
Arthritis	0.280 (0.455)	1.323 (0.543 – 3.225)	0.538	1.316 (0.344)	3.730 (1.902 – 7.315)	<0.0001
CVD/HTN	-0.798 (0.604)	0.450 (0.138 – 1.472)	0.187	0.236 (0.377)	1.266 (0.605 – 2.648)	0.532
Diabetes	-0.411 (0.399)	0.663 (0.303 – 1.448)	0.302	0.721 (321)	2.057 (1.098 – 3.857)	0.024
Others	-1.437 (1.170)	0.238 (0.024 – 2.354)	0.219	0.521 (0.718)	1.683 (0.412 – 6.881)	0.469
Comorbidities						
Arthritis	-0.579 (0.561)	0.561 (0.187 – 1.682)	0.302	-0.159 (0.344)	0.853 (0.435 – 1.675)	0.645
CVD/HTN	0.356 (0.454)	1.428 (0.586 – 3.479)	0.433	0.637 (0.344)	1.890 (0.962 – 3.73)	0.065
Diabetes	0.983 (0.463)	2.673 (1.078 – 6.627)	0.034	0.928 (0.397)	2.528 (1.162 – 5.503)	0.019
Others	-0.437 (0.733)	0.646 (0.154 – 2.716)	0.551	0.067 (0.537)	1.069 (0.373– 3.065)	0.901
Energy (kcals/d)	0.003 (0.001)	1.003 (1.002– 1.005)	<0.0001	0.002 (0.001)	1.002 (1.001 – 1.003)	0.001
Protein (g/d)	-0.064 (0.021)	0.938 (0.893 – 0.986)	0.012	-0.083 (0.019)	0.921 (0.887 – 0.956)	<0.0001
Carbohydrates (g/d)	-0.009 (0.005)	0.991 (0.980 – 1.001)	0.092	-0.007 (0.004)	0.993 (0.985 – 1.000)	0.062
Fat (g/d)	-0.021 (0.008)	0.979 (0.963 – 0.995)	0.011	-0.011 (0.006)	0.998 (0.997 – 0.999)	0.086
Calcium (mg/d)	0.000 (0.001)	1.000 (0.998 – 1.002)	0.807	-0.002 (0.001)	0.998 (0.997 – 0.999)	0.005
Iron (mg/d)	-0.059 (0.086)	0.942 (0.797 – 1.115)	0.488	0.059 (0.055)	1.061 (0.952 – 1.183)	0.286

CVD/HTN – cardiovascular disease/hypertension

Prevalence of Obese and Non-obese Sarcopenia

We found 20.6% of our participants to have sarcopenic obesity/overweight as per SWAG-SARCO. This figure is much higher than the previous studies conducted in India where the prevalence ranged between 0.6 to 8.7%.[4,10,15,22] Using the AWGS criteria, the prevalence of sarcopenic obesity/overweight in the present study was 5%. There are many reasons for this high prevalence. Firstly, previous studies have used either the European or the Asian consensus for the diagnosis of sarcopenia. As mentioned earlier, AWGS uses muscle mass as the primary criteria for the diagnosis while South Asian guidelines emphasize equally on all three components (muscle mass, muscle strength and muscle function). Thus, with the use of AWGS, it is highly likely to miss individuals with normal muscle mass but low muscle strength and muscle function. Secondly, studies vary in their measurement methods used for muscle mass (DEXA/BIA). Unlike the earlier studies, we used calf circumference as an indicator of muscle mass. Calf circumference is a simple measurement which can be used conveniently in clinical and community settings. SWAG-SARCO consensus recommended use of "clinical and economic" tools like calf circumference which correlates with the skeletal muscle mass.[2] Further, the consensus paper also suggests that fat mass present around the site of measurement should be eliminated to obtain the actual calf circumference. This is more so true for individuals who are overweight or obese. Using unadjusted calf circumference may underestimate the prevalence of sarcopenia in overweight/obese and overestimate it in underweight individuals.[25] Therefore, we adjusted the calf circumference for BMI to derive more realistic muscle mass estimates. Fourthly, age of the participants differed largely. Thirdly, the selection criteria of the participants were also varied. For example, Pal[4] recruited healthy adults without comorbidities while others did not exclude individuals with comorbidities. Lastly, the variation could be due the use of body fat (%) or waist circumference for classification of obesity and the age of the participants. We used the Asian classification to classify the BMI as this was more suitable to the ethnicity of the participants.[26]

Much of the available literature focussed on sarcopenic obesity. India is known to have been facing the double burden of malnutrition. Considering this, we also found nearly 10% of our participants with sarcopenia to be underweight or with a normal BMI. A study conducted in West China reported 16.7% participants over 50 years who were non-obese to have sarcopenia.[16] Another study done among Thai older adults found 8.1% and 16% participants who were underweight and normal BMI respectively who had possible sarcopenia. The study also highlighted that the underweight individuals with sarcopenia had highest risk of increased mortality (adjusted hazard ratio: 3.98, 95% CI: 2.89–5.48).[18] However, in the present study we found 1.8% (n = 8) individuals who were underweight and had sarcopenia.

Influence of Age on Obese and Non-Obese Sarcopenia

We found that age increased the odds of having sarcopenia irrespective of the BMI status. Several studies have reported age to be a predictor of sarcopenia[16,20,28] and sarcopenic obesity.[8,15,16,20] All these studies were conducted among individuals over 38 years. Besides the age-related decline in muscle mass, loss of muscle strength has also been observed secondary to physical inactivity. Ageing process has been associated with loss of fast-twitch muscle fibres as compared to slow-twitch ones as well as decrease in muscle fibre size. Besides these changes, ageing is considered as a mild inflammatory state. Studies suggest that elevated levels of inflammatory makers such as tumour necrosis factor – α, C-reactive protein, interleukin – 6 stimulated muscle protein breakdown leading to muscle atrophy. Moreover, anabolic hormones that stimulate protein synthesis such as growth hormone, insulin-like growth factor – 1, sex hormones such as estrogen and testosterone have also been noted to decrease with age and obesity.[6,29]

Influence of Diabetes on Obese and Non-Obese Sarcopenia

In addition to aging and inflammation, obesity has also been associated with insulin resistance. Individuals with insulin resistance were seen to have a higher risk of loss of muscle mass as compared to non-insulin resistant individuals thus, aggravating the risk of sarcopenia.[30] Consistent with this, we found individuals with obesity and diabetes to have 2.5 times greater odds (95% CI: 1.162 – 5.503, p = 0.019) of developing sarcopenic obesity. Yogesh[20] also reported 2.4-fold greater odds (95% CI: 1.1-5.0) of sarcopenic obesity after adjustment

for covariates. Insulin is also an anabolic hormone which decreases with age. This can probably explain why non-obese people with diabetes also had 2.6 times higher odds (95% CI: 1.078 – 6.627; p = 0.034) of having sarcopenia. Further, longer duration of diabetes and uncontrolled blood glucose levels increase the risk for sarcopenia with or without obesity.

Influence of Energy Intake on Obese and Non-Obese Sarcopenia

We found that higher energy intake increased the odds of developing sarcopenic irrespective of the BMI. We know that as age increases, the body's resting energy expenditure decreases and so does the caloric requirement. Higher energy intake is associated with increased body mass and inflammation. This can explain the relationship between energy intake and sarcopenia.

Influence of Protein Intake on Obese and Non-Obese Sarcopenia

Much like the previous studies, our present findings also support the protective role of protein in development of sarcopenic irrespective of the BMI of the participants. High protein intakes support the increase in muscle mass.[31–34] Skeletal muscle constantly oscillates between protein synthesis and breakdown in the fed and the fasting state respectively. Adequate protein quantity and quality are pivotal in muscle protein synthesis. In the present study, participants were seen to consume 0.55 g/kg body weight/d. The recommended dietary allowance (RDA) of protein is 0.8 g/kg/d. RDA is considered to be the minimum amount of protein required to meet the requirement of all the essential amino acids to attain nitrogen balance and preserve muscle mass in 97.5% of the population. Higher protein intake i.e. greater than the RDA and within the adequate macronutrient distribution range has been associated with muscle accretion.[31–33] In addition to the daily protein intake, per meal protein content (0.24 to 0.4 g/kg) is likely to create a favourable anabolic environment. Among the essential amino acids, leucine is known to regulate the mTOR signalling pathway that stimulates muscle protein synthesis.[34] Indian diets are known to be poor in terms of both, protein quantity and quality. In such a scenario, it becomes imperative for the diet to meet the requirements of all the essential amino acids to enable muscle protein synthesis in the body.

Other Factors Influencing Sarcopenic Obesity

Aging and obesity both have been associated with inflammation. As mentioned earlier, elevated inflammatory markers and decreased anabolic hormones causes muscle protein breakdown leading to muscle atrophy and hampers muscle protein synthesis.

It is interesting to note that, in people who are obese, the additional load (i.e. fat mass) is likely to have a positive effect on the skeletal muscles at a young age. In the young, this extra load has an advantage by acting as resistance and stimulating skeletal muscle thus enhancing the strength in the antigravity muscles such as quadriceps, calf, back extensors and oblique abdominals. However, over a period of time, the cumulative effect of this additional load with inflammation, drop in anabolic hormones and elevated intramuscular fat resulted in reduced muscle strength.[29] Thus, individuals with overweight/ obesity were seen to have poorer ratio of strength to body mass as compared to the non-obese.[6] Also, beyond a certain threshold of the additional load, there could be 'obesity-induced muscle anabolic resistance' resulting in rapid decline in the muscle mass. The impact of lower muscle strength and additional load on the joints was seen to increase their risk for arthritis.[29] Poor joint health could lead to restricted movement and functional impairment thus aggravating the progression of sarcopenia. In the present study too, individuals with family history of arthritis were seen to have higher odds of sarcopenia (OR - 3.730 95% CI:1.902 – 7.315; p < 0.001).

Among the protective factors, in addition to dietary protein, higher intake of calcium was also seen to be significant (p = 0.005). Higher dietary calcium has been associated with better skeletal muscle mass and strength.[35,36] Further, participants with higher calcium intake and muscle strength reported lower body fat percentage.[36] This explains the relationship of dietary calcium with sarcopenia in obese individuals.

Other Factors Influencing Non-Obese Sarcopenia

In the present study, females had 2.3 times greater odds (95% CI: 1.170 – 4.848; p = 0.017) of having non-obese sarcopenia as compared to males. Petermann-Rocha[28] also found females at a higher risk of developing sarcopenia. However, they did

not consider the BMI of the participants. One of the reasons that may predispose women to a higher risk is the sudden drastic decline in the anabolic hormone, estrogen during menopause. Though we did not elicit the menstrual history of the participants, considering their age, they are likely to be in the menopausal stage. The rise in abdominal obesity among adult females in particular is also a cause for concern.[17]

Dietary fat intake was noted to be protective against sarcopenia in individuals who were non-obese. We did not study the fatty acid profile of the diets of our participants. However, the protective nature of dietary fats can be attributed to the intake of mono unsaturated fatty acids and n-3 fatty acids in particular. Both have been documented to improve muscle health and physical function by preventing muscle atrophy.[37] This is related to the anti-inflammatory and anti-oxidant function of these fatty acids.

The strength of our study lies in the use of the SWAG-SARCO consensus which is more suited for the Indian ethnicity. As equal emphasis is laid on all the three components of muscle health, this consensus may identify sarcopenia cases missed by other guidelines. Further, we used reliable yet, simple and economic measurements to identify people with sarcopenia. These measurements can be incorporated in to regular screening in community and clinical settings particularly in resource poor countries. We adjusted the calf circumference to BMI to eliminate the effect of adiposity. This can help us identify the genuine cases of sarcopenia and minimize the error. To the best of our knowledge, this is one of the earlier studies to have used the South Asian guidelines for diagnosis of sarcopenia. We also studied the influence of dietary intake on obese and non-obese sarcopenia. Ours is one of the earliest studies to analyze the factors influencing non-obese sarcopenia. The limitation was of our study was the study location. We studied participants in one Indian city – Bengaluru. However, Bengaluru is a metropolitan city and is often referred to as the Silicon Valley of India owing to the various IT companies and start-ups housed here. Therefore, the study possibly reflects the situation in other metropolitan cities in India too.

Conclusion

We found 20% of the participants had sarcopenic obesity and 10% had non-obese sarcopenia. Considering the changing demography of India, sarcopenic obesity seems to be a growing concern. These findings should be viewed from the prism of the influence of age on sarcopenia and India's growing aging population. Nutritional factors such as energy, protein, fat and calcium intake influenced the prevalence of obese and non-obese sarcopenia. Traditionally, much of the focus of disease prevention has been on reduction of body fat mass. However, body fat loss is not always accompanied with increase in muscle mass. It is time to also focus on the muscle health. In India, the availability of BIA/DEXA is restricted to selected settings. Use of ethnicity-specific guidelines along with practical, economical and reliable tools such as calf circumference would aid in effective diagnosis. Hence, we need to emphasize on regular screening of people for sarcopenia. Focus also needs to brought back on modifiable factors such as nutrient intake and physical activity. Healthcare professionals need to change the narrative of the health communication messages to emphasize on muscle health as well.

Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement

The study was approved by the Institutional Human Ethical Committee (IHEC), Mount Carmel College,

Autonomous Bengaluru. (IHEC-MCC No. 018 M.Sc./2021-22).

Informed Consent Statement
Written informed consent was obtained from the participants for inclusion in the study as well as for publishing the data.

Clinical Trial Registration
This research does not involve any clinical trials.

Permission to Reproduce Materials from Other Sources
Not applicable.

Author Contributions
- **Mitravinda Savanur:** conceptualization, designing the study, manuscript preparation and editing
- **Tanushree Jain:** data collection, statistical analysis, manuscript review
- **Ashika Mysore Krishna:** data collection, statistical analysis, manuscript review
- **Safiya Arfain Kaniyambadi:** data collection, statistical analysis, manuscript review

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