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Association of central obesity and high body mass index with function and cognition in older adults

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Abstract

Objective: To investigate the association of normal BMI with central obesity (CO), high BMI with CO, high BMI without CO, and normal BMI without CO, with function and cognition in older adults.

Methods: Cross-sectional study involving 754 participants ≥ 65 years. Data collected include demographics, cognition, and physical measurements.

Results: Females had a higher prevalence of high BMI with CO and a lower prevalence of high BMI without CO than males (61.0% vs 44.6% and 4.6% vs 15.0%, respectively). Within gender, CO groups, regardless of BMI, had lower mini-mental state examination (MMSE), handgrip strength (HGS), and longer timed-up-and-go (TUG) scores. Overall, the high BMI without CO group had the highest MMSE scores, HGS, and shortest TUG. Amongst males, HGS was significantly lower in the normal BMI with CO group (B −3.28, 95% CI −6.32 to −0.23, $P = 0.04$). CO, regardless of normal/high BMI, had significantly longer TUG time (B 2.65, 95% CI 0.45 to 4.84, $P = 0.02$; B 1.07, 95% CI 0.25 to 1.88, $P = 0.01$, respectively) than normal BMI without CO group. CO was associated with lower MMSE scores in both genders but significant only in males with normal BMI and CO (B −1.60, 95% CI −3.15 to −0.06, $P = 0.04$).

Conclusion: CO may be a better predictor of obesity and adverse outcomes in older adults. High BMI without CO was associated with better outcomes especially in males but require further validation. Prospective longitudinal studies are needed to ascertain the impact of BMI and/or CO on function, cognition, mortality, and gender differences.

Introduction

Worldwide, the prevalence of obese and overweight adults continue to increase, affecting at least one in three men and women (1). Both are known to be independently associated with adverse outcomes such as reduced life expectancy, mortality, disability, poor quality of life, increased healthcare utilisation, and cardio-metabolic diseases such as diabetes and ischaemic heart disease (2, 3). While it is known that many obese individuals will develop cardio-metabolic health problems, there is a proportion of adults who remain free of diseases and are described to have metabolically healthy obesity (MHO).

BMI is often used as a measure of obesity in daily practice but should be interpreted with caution as it may be a poor indicator of fat distribution, especially in older adults. High BMI is associated with better survival and cognition in older adults (4, 5, 6). Waist circumference (WC) reflects central obesity (CO), which is a risk factor for adverse outcomes including mortality independent of BMI

and may be a better measure of obesity (7). The prevalence of CO continues to increase worldwide outpacing BMI, and by 2030, the prevalence is projected to be 55.6% in men and 80.0% in women in the US (8, 9). Many studies have shown a 'U-shaped' curve for the relationship of BMI and mortality, and linear relationship between WC and mortality (10). Mortality rates in older obese adults were found to be lower than young obese adults (11). High-intensity interval training and aerobic exercises at least three times a week have shown to be effective in reducing visceral adipose tissue (12).

There are different impacts of high BMI and CO on physical function and cognition in the young and old (13). There is still an ongoing debate on the usefulness of measuring BMI as an indicator of obesity, and the cut-off for BMI in older adults. This study aims to examine the demographic factors and investigate the association of normal BMI with CO, high BMI with CO, high BMI without CO, and normal BMI without CO with function and cognition in older adults.

Methods

The study population is a subgroup of the Healthy Older People Everyday (HOPE) cohort, which was part of the Singapore Population Health Studies – Community Health Study, conducted between April 2015 and August 2016 (14). The initial HOPE study was a cross-sectional and nationally representable cohort of 1051 older adults ≥ 65 years old, recruited from a defined geographical area in the Northwest of Singapore. Only 754 participants with available measurements on waist circumference (WC) and BMI were included in the current analysis. Further details on recruitment, interview questionnaire, physical and cognitive assessment were elaborated in prior published studies (14, 15).

Interview questionnaires consisting of demographics, education level, chronic diseases, medications, falls, activities and instrumental activities of daily living, cognition, frailty, and perceived health were collected. It was administered by trained research staff and relied on self-reported data. Multimorbidity was defined by the presence of ≥2 or more chronic illnesses while polypharmacy was defined by ≥5 prescribed medications daily. Nutritional risk was assessed using the 3-min nutritional screening (3-MinNS) tool (16). Physically active was defined based on WHO recommendations of doing at least 150 min of moderate intensity or 75 min of vigorous intensity aerobic physical activity per week (17). Activities of daily living

(ADL) and instrumental activities of daily living (IADL) were evaluated using the Barthel Index and Lawton's IADL scale, respectively (18, 19). Cognition was assessed using the mini-mental state examination (MMSE) (20). Frailty was assessed using the 5-item FRAIL scale (fatigue, resistance, ambulation, illness, and loss of weight) which has been validated in many countries (14, 21). Perceived general health was measured using the EuroQol Visual Analogue Scale (22).

Participants were invited for physical assessment which consisted of height, weight, WC, timed-up-and-go (TUG) test (23), and hand grip strength (HGS). WC was measured midpoint between the last rib and iliac crest. The HGS was measured three times in each hand using a digital dynamometer (A5401, Takei Scientific Instruments Co., Ltd., Japan), and the maximum grip strength of the dominant hand was included in the analysis. Relative HGS was defined as the maximum grip strength of dominant hand over body weight (15).

According to WHO recommendations for Asians (24), the cut-off for normal BMI was 23.0 kg/m^2 and any value above this was regarded as high BMI. CO was defined by WC ≥ 90 cm for men and ≥ 80 cm for women according to International Diabetes Federation recommendations for Asians (25).

The research study complies with the Declaration of Helsinki's ethical principles. All procedures and purposes of the study were explained, and written consent was obtained from all recruited participants. The study protocol was approved by the National Healthcare Group (NHG), Domain-Specific Review Board (DSRB), Singapore.

Statistical analysis

The dataset was analysed using IBM SPSS Version 26.0. Categorical variables were presented as frequencies (%), while continuous variables were stated as means ± S.D. Chi-squared test, with Bonferroni correction, and one-way ANOVA, with Tukey's test, were used to determine significant differences between independent groups for categorical and continuous variables, respectively.

Sub-group analyses were carried out for both genders. Univariate and multivariate linear regression models were used to evaluate mean differences between BMI groups, with and without CO, on HGS, relative HGS, TUG, and MMSE. Normal BMI without CO was set as the reference group. The mean differences between the groups and the reference were reflected as B-coefficients with 95% CIs included in all models. The multivariate models were adjusted for age, education, height, physical activity, and

hypertension. Statistical significance was determined as $P < 0.05$.

Results

Our study involved 754 community-dwelling older adults ≥ 65 years old, mean age 70.8 ± 5.1 years, mean education 6.3 ± 4.4 years, 54.8% female, and 82.2% of Chinese ethnicity. As seen in Table 1, 53.6% ($n=404$) had high BMI with CO, 30.4% ($n=229$) had normal BMI without CO, 9.3% ($n=70$) had high BMI without CO,

and 6.8% ($n=51$) had normal BMI with CO. Obesity prevalence defined by WC was 60.4% and BMI 62.9%.

There was a higher prevalence of high BMI with CO amongst females compared with males, 61.0% and 44.6%, respectively. Amongst the male, 37.0% belonged to the normal BMI without CO group compared with 24.9% females. Almost one in three of the Chinese ethnic group belonged to the normal BMI without CO group, compared to one in five Indian and one in seven of the Malay ethnic groups.

The high BMI with CO group had more significant associations with other health indices than the normal

Table 1 Characteristics of participants.

		Normal BMI		High BMI		
Variable	**All, *n* = 754** (100%)	No central obesity, *n* = 229 (30.4%) (normal BMI without CO)	Central obesity, *n* = 51 (6.8%) (normal BMI with CO)	No central obesity, *n* = 70 (9.3%) (high BMI without CO)	Central obesity, *n* = 404 (53.6%) (high BMI with CO)	**P value**
Age, mean	70.8 ± 5.1	71.1 ± 5.3	71.3 ± 4.9	70.2 ± 4.8	70.6 ± 5.0	0.37
Gender[a]						**<0.01**
Male	341 (100.0)	126 (37.0%)	12 (3.5%)	51 (15.0%)	152 (44.6%)	
Female	413 (100.0)	103 (24.9%)	39 (9.4%)	19 (4.6%)	252 (61.0%)	
Ethnicity[a]						**<0.01**
Chinese	620 (100.0)	204 (32.9)[A, C]	49 (7.9)[B, D]	58 (9.4)	309 (49.8)[A, B, C, D]	
Malay	43 (100.0)	6 (14.0)[A]	1 (2.3)	4 (9.3)	32 (74.4)[A]	
Indian	46 (100.0)	10 (21.7)	1 (2.2)	4 (8.7)	31 (67.4)	
Others	45 (100.0)	9 (20.0)	0 (0.0)	4 (8.9)	32 (71.1)	
Education (years), mean	6.3 ± 4.4	6.8 ± 4.3[A]	5.7 ± 4.4	7.3 ± 4.5	5.9 ± 4.4[A]	**0.02**
Hypertension	563 (74.7)	137 (59.8)[A, B]	36 (70.6)	58 (82.9)[A]	332 (82.2)[B]	**<0.01**
Hyperlipidaemia[b]	429 (56.9)	107 (46.7)[A]	33 (64.7)	43 (61.4)	246 (60.9)[A]	**0.02**
Diabetes	231 (30.6)	47 (20.5)[A]	15 (29.4)	17 (24.3)	152 (37.6)[A]	**<0.01**
Stroke[c]	23 (3.1)	5 (2.2)	0 (0.0)	1 (1.4)	17 (4.2)	0.16
Heart attack[d]	37 (4.9)	10 (4.4)	3 (5.9)	4 (5.7)	20 (5.0)	0.89
Multimorbidity	522 (69.2)	130 (56.8)[A]	33 (64.7)	47 (67.1)	312 (77.2)[A]	**<0.01**
Polypharmacy	103 (13.7)	25 (10.9)	10 (19.6)	5 (7.1)	63 (15.6)	0.08
Frailty status						0.27
Robust	438 (58.1)	141 (61.6)	29 (56.9)	46 (65.7)	222 (55.0)	
Pre-frail	274 (36.3)	80 (34.9)	17 (33.3)	21 (30.0)	156 (38.6)	
Frail	42 (5.6)	8 (3.5)	5 (9.8)	3 (4.3)	26 (6.4)	
Nutritional risk (3-MinNS ≥ 3)	22 (2.9)	13 (5.7)[A, B]	1 (2.0)	0 (0.0)[A]	8 (2.0)[B]	**0.02**
At least one ADL impairment	128 (17.0)	33 (14.4)	9 (17.6)	10 (14.3)	76 (18.8)	0.49
At least one IADL impairment	292 (38.7)	93 (40.6)	16 (31.4)	25 (35.7)	158 (39.1)	0.62
Falls (≥1 in past year)	92 (12.2)	23 (10.0)	8 (15.7)	6 (8.6)	55 (13.6)	0.36
Physically active	127 (16.8)	52 (22.7)[A]	7 (13.7)	13 (18.6)	55 (13.6)[A]	**0.03**
MMSE score, mean	27.0 ± 3.0	27.4 ± 2.9[A]	26.6 ± 3.6	27.5 ± 3.0	26.7 ± 3.0[A]	**0.02**
Perceived health (EQ-VAS), score	80.7 ± 14.5	79.2 ± 14.9	80.6 ± 12.6	82.6 ± 13.2	81.2 ± 14.7	0.27
Grip strength (kg), mean	22.5 ± 6.8	23.1 ± 6.8[A, B]	19.9 ± 5.8[A, C]	26.5 ± 6.8[B, C, D]	21.8 ± 6.7[D]	**<0.01**
Relative grip strength (kg), mean	0.37 ± 0.11	0.44 ± 0.10[A, B]	0.36 ± 0.09[A, C]	0.43 ± 0.09[C, D]	0.32 ± 0.08[B, D]	**<0.01**
TUG (s), mean	11.3 ± 4.0	10.7 ± 4.6[A]	11.1 ± 3.4	10.4 ± 2.9[B]	11.8 ± 3.8[A, B]	**<0.01**

Bold indicates significance; Values are *n* (%), otherwise mean ± S.D.
Each uppercase superscript letters denotes significant difference from each other at $P < 0.05$; [a]Row %, otherwise column %; [b]*n* = 738; [c]*n* = 752; [d]*n* = 749.
3-MinNS, 3-min nutrition screening; ADL, activities of daily living; CO, central obesity; EQ-VAS, EuroQol visual analogue scale; IADL, instrumental activities of daily living; MMSE, mini Mental state examination; TUG, timed up and go.

BMI without CO group. There was a significantly higher prevalence of hypertension (82.2% vs 59.8%) and diabetes (37.6% vs 20.5%) in the high BMI with CO group compared with the normal BMI without CO group. In the subgroup analysis (Supplementary Table 1, see section on supplementary data given at the end of this article), diabetes prevalence remained significant only in females. There was a significantly higher prevalence of multimorbidity in the high BMI with CO compared with normal BMI without CO; 77.2% and 56.8%, respectively.

Amongst the normal BMI without CO group, 22.7% were physically active compared with 13.6% of the high BMI with CO group. The difference remained significant for females where 29.1% of the normal BMI without CO group were physically active compared with 12.3% of the high BMI with CO group. Although not statistically significant, the prevalence of frailty was highest in the normal BMI with CO group (9.8%) followed by high BMI with CO (6.4%), high BMI without CO (4.3%), and normal BMI without CO group (3.5%). The indices for falls were also highest in the normal BMI with CO group (15.7%), and lowest in the high BMI without CO group (8.6%). There was a significantly higher prevalence of risk of malnutrition in the normal BMI without CO group (5.7%) compared with the high BMI with CO (2.0%) and normal BMI with CO groups (2.0%).

Mean TUG was significantly longer in the high BMI with CO group (11.8 ± 3.8 s), and shortest in the high BMI without CO group (10.4 ± 2.9 s). However, there were gender differences where in male, TUG was longest in the normal BMI with CO group (12.7 ± 5.2 s) and shortest in the high BMI without CO group (10.2 ± 2.8 s) (Supplementary Table 1). In females, TUG was longest in the high BMI with CO group (12.1 ± 4.1 s) and shortest in the normal BMI without CO group (10.4 ± 5.0 s). With both genders combined, HGS was lowest in the normal BMI with CO group (19.9 ± 5.8 kg) and highest in the high BMI without CO group (26.5 ± 6.8 kg).

Relative HGS was significantly lower in the high BMI with CO and normal BMI with CO group, compared with high BMI without CO and normal BMI without CO group, 0.32 ± 0.08 kg, 0.36 ± 0.09 kg, 0.43 ± 0.09 kg, and 0.44 ± 0.10 kg, respectively. For females, there was no significant difference in the HGS between the groups. Both the high BMI with CO and normal BMI with CO groups had significantly lower MMSE scores compared with high BMI without CO and normal BMI without CO groups, 26.7 ± 3.0, 26.6 ± 3.6, 27.5 ± 3.0, and 27.4 ± 2.9, respectively.

Tables 2, 3, 4 and 5 summarises the unadjusted and adjusted models of grip strength, relative grip strength, TUG, and MMSE.

Unadjusted, males in high BMI without CO group had higher HGS compared with the normal BMI without CO group (B 2.35, 95% CI 0.49 to 4.21, $P = 0.01$) (Table 2). After adjusting for age, education, height, physical activity, and hypertension, males in the normal BMI with CO group had lower HGS than those in the normal BMI without CO group (B −3.28, 95% CI −6.32 to −0.23, $P = 0.04$). After adjustment, both males and females in the high BMI with CO and normal BMI with CO groups had lower relative HGS; male high BMI with CO (B −0.11, 95% CI −0.13 to −0.09, $P < 0.01$), male normal BMI with CO (B −0.10, 95% CI −0.15 to −0.05, $P < 0.01$), female high BMI with CO (B −0.09, 95% CI −0.10 to −0.07, $P < 0.01$) and female normal BMI with CO (B −0.03, 95% CI −0.06 to 0.00, $P = 0.09$ (Table 3). Adjusted relative HGS amongst males in the high BMI without CO group was significantly lower (B −0.04, 95% CI −0.07 to −0.01, $P < 0.01$) than those with normal BMI without CO.

After adjustment, males in the normal BMI with CO and high BMI with CO group had significantly longer TUG time (B 2.65, 95% CI 0.45 to 4.84, $P = 0.02$) and (B 1.07, 95% CI 0.25 to 1.88, $P = 0.01$) respectively compared with the normal BMI without CO group (Table 4). Similarly, MMSE

Table 2 Unadjusted and adjusted B-coefficients, with 95% CI, of grip strength in BMI groups with/without central obesity, by gender.

	Normal BMI		High BMI	
	No central obesity (normal BMI without CO)	Central obesity (normal BMI with CO)	No central obesity (high BMI without CO)	Central obesity (high BMI with CO)
Males, unadjusted	0 (Reference)	−1.99 (−5.43 to 1.46) $P = 0.26$	**2.35 (0.49 to 4.21)** **$P = 0.01$**	0.61 (−0.78 to 2.00) $P = 0.39$
Males, adjusted	0 (Reference)	**−3.28 (−6.32 to −0.23)** **$P = 0.04$**	1.74 (−0.01 to 3.49) $P = 0.05$	0.12 (−1.30 to 1.54) $P = 0.87$
Females, unadjusted	0 (Reference)	0.09 (−1.54 to 1.72) $P = 0.92$	0.44 (−1.55 to 2.42) $P = 0.67$	−0.03 (−0.96 to 0.90) $P = 0.95$
Females, adjusted	0 (Reference)	0.05 (−1.52 to 1.62) $P = 0.95$	1.48 (−0.31 to 3.28) $P = 0.10$	0.19 (−0.70 to 1.09) $P = 0.67$

Bold indicates significance; Adjusted for age, education, height, physical activity, and hypertension.
CO, central obesity; Reference group, normal BMI without CO.

Table 3 Unadjusted and adjusted B-coefficients, with 95% CI, of relative grip strength in BMI groups with/without central obesity, by gender.

	Normal BMI		High BMI	
	No central obesity (normal BMI without CO)	Central obesity (normal BMI with CO)	No central obesity (high BMI without CO)	Central obesity (high BMI with CO)
Males, unadjusted	0 (Reference)	**−0.09 (−0.14 to −0.03)** **P < 0.01**	−0.02 (−0.06 to 0.01) P = 0.11	**−0.11 (−0.13 to −0.09)** **P < 0.01**
Males, adjusted	0 (Reference)	**−0.10 (−0.15 to −0.05)** **P < 0.01**	**−0.04 (−0.07 to −0.01)** **P = 0.01**	**−0.11 (−0.13 to −0.09)** **P < 0.01**
Females, unadjusted	0 (Reference)	**−0.04 (−0.07 to 0.00)** **P = 0.03**	**−0.05 (−0.09 to −0.01)** **P = 0.01**	**−0.09 (−0.11 to −0.07)** **P < 0.01**
Females, adjusted	0 (Reference)	−0.03 (−0.06 to 0.00) P = 0.09	−0.04 (−0.08 to 0.00) P = 0.06	**−0.09 (−0.10 to −0.07)** **P < 0.01**

Bold indicates significance; Adjusted for age, education, height, physical activity and hypertension.
CO, central obesity; Reference group, normal BMI without CO.

scores were generally lower in the presence of CO in both genders. After adjustment, significance was observed only in males with normal BMI and CO (B −1.60, 95% CI −3.15 to −0.06, $P = 0.04$).

Discussion

The prevalence of CO in our older adults was 60.4%, which is similar to other studies ranging from 62 to 65.1% (26). Slightly more than half had both high BMI and CO. CO in isolation or in combination with high BMI was associated with lower cognitive scores, lower HGS and relative HGS, and longer TUG. There were gender differences in the overall prevalence and associations. Amongst females, 61.0% belonged to the high BMI with CO group compared with 44.6% of males, and 4.6% to the high BMI without CO group compared with 15.0% of males. Interestingly, males in the high BMI without CO group performed better on the functional and cognitive test, with the lowest performance in the normal BMI with CO group. In females, there were no significant differences in the cognitive scores and HGS

between groups except TUG being longest in the high BMI with CO group and shortest in the normal BMI without CO group, and lower relative HGS in the high BMI with CO, high BMI without CO and normal BMI with CO groups.

There was a higher prevalence of CO in older adults with high BMI in our participants. Adipose tissue is pro-inflammatory, and aging is also associated with low-grade inflammation with an increase in visceral adipose tissue, ectopic fat distribution, and redistribution of body fat (27). CO, through its 'inflammaging' effect, is associated with disability and mortality. It is associated with lower lung function, and in a most recent study, abdominal obesity measured by increased waist-hip ratio and not metabolic syndrome was associated with increased respiratory deterioration in COVID-19 (28, 29). WC and abdominal obesity are also associated with vertebral fracture risk (30). While in younger adults high BMI is associated with increased morbidity and mortality, mortality was higher in older adults with a lower range of recommended BMI and lower in those with higher BMI (4, 31). High BMI between 25.0 and 34.9 kg/m² has also been shown to be associated with lower mortality in frail older women (32).

Table 4 Unadjusted and adjusted B-coefficients, with 95% CI, of TUG in BMI groups with/without central obesity, by gender.

	Normal BMI		High BMI	
	No central obesity (normal BMI without CO)	Central obesity (normal BMI with CO)	No central obesity (high BMI without CO)	Central obesity (high BMI with CO)
Males, unadjusted	0 (Reference)	1.80 (−0.75 to 4.35) P = 0.16	−0.69 (−1.94 to 0.57) P = 0.28	0.55 (−0.30 to 1.39) P = 0.21
Males, adjusted	0 (Reference)	**2.65 (0.45 to 4.84)** **P = 0.02**	0.27 (−0.95 to 1.48) P = 0.66	**1.07 (0.25 to 1.88)** **P = 0.01**
Females, unadjusted	0 (Reference)	0.23 (−1.45 to 1.91) P = 0.79	0.62 (−1.73 to 2.97) P = 0.60	**1.68 (0.66 to 2.69)** **P < 0.01**
Females, adjusted	0 (Reference)	−0.71 (−2.37 to 0.96) P = 0.40	0.19 (−2.14 to 2.53) P = 0.87	0.90 (−0.06 to 1.85) P = 0.07

Bold indicates significance; Adjusted for age, education, height, physical activity and hypertension.
CO, central obesity; Reference group, normal BMI without CO; TUG, timed up and go.

Table 5 Unadjusted and adjusted B-coefficients, with 95% CI, of MMSE Score in BMI groups with/without central obesity, by gender.

	Normal BMI		High BMI	
	No central obesity (normal BMI without CO)	Central obesity (normal BMI with CO)	No central obesity (high BMI without CO)	Central obesity (high BMI with CO)
Males, unadjusted	0 (Reference)	−1.08 (−2.66 to 0.49) $P = 0.18$	0.07 (−0.71 to 0.85) $P = 0.86$	−0.10 (−0.62 to 0.43) $P = 0.72$
Males, adjusted	0 (Reference)	**−1.60 (−3.15 to −0.06)** **$P = 0.04$**	−0.06 (−0.87 to 0.75) $P = 0.88$	−0.31 (−0.86 to 0.24) $P = 0.26$
Females, unadjusted	0 (Reference)	−0.28 (−1.54 to 0.97) $P = 0.65$	−0.61 (−2.34 to 1.12) $P = 0.49$	**−0.79 (−1.55 to −0.03)** **$P = 0.04$**
Females, adjusted	0 (Reference)	0.09 (−1.08 to 1.26) $P = 0.88$	−0.03 (−1.61 to 1.55) $P = 0.97$	−0.14 (−0.84 to 0.56) $P = 0.69$

Bold indicates significance; Adjusted for age, education, height, physical activity and hypertension.
CO, central obesity; MMSE, mini mental state examination; Reference group, normal BMI without CO.

The association of HGS in metabolic syndrome and obesity is an evolving area of research where recent studies suggest that relative HGS measured by either HGS/BMI or HGS/body weight may better predict negative outcomes in obese older adults (15). Male in the high BMI without CO group had significantly higher HGS than the normal BMI without CO group but was no longer significant after adjusting for confounding factors. However, males in the normal BMI with CO group had significantly lower HGS even after adjustment which further supports the role of 'inflammaging' and intramuscular fat distribution affecting muscle quality (33). Relative HGS may be an early marker of muscle quality and was low in the high BMI with CO and normal BMI with CO groups.

The high BMI without CO group in our study, especially males, had higher HGS and shorter TUG compared with the normal BMI with CO and high BMI with CO group. High BMI in older adults has been associated with increased survival and better cognitive scores (4, 5). The high BMI without CO group in our study also had higher MMSE scores, which has also been shown in previous studies. CO is reflective of visceral fat and is associated with increased mortality and lower cognitive scores (5, 32, 34). Previous studies have shown that those with CO and high BMI are at increased risk of cognitive impairment (35). In our study, both the normal BMI with CO and high BMI with CO groups had lower cognitive scores. In the multivariate model, the male normal BMI with CO group had significantly lower MMSE compared with the normal BMI without CO group. If BMI is used as the only measure for obesity, 6.8% of the population with CO and normal BMI would have been excluded from any interventions and our study has shown that this group is at high risk of negative outcomes.

Being overweight in older adults may reflect better nutritional status whereas weight loss is associated with

frailty and increased mortality (31, 32). The normal BMI without CO group had about 2.5 times higher risk of malnutrition compared with the normal BMI with CO or high BMI with CO groups, and 5.7 times compared with the high BMI without CO group. Frailty prevalence in the normal BMI with CO group was almost three times higher than that of the normal BMI without CO and double compared with the high BMI without CO group. Many studies, including a recent study by Alfonso *et al.*, showed that frailty is highly associated with 'general and abdominal obesity' where general obesity was defined as BMI ≥ 30.0 kg/m^2 (36). The same group also had low HGS (37). Our study also revealed similar findings where the normal BMI with CO group had the highest frailty prevalence and the high BMI without CO group had the highest HGS.

Our study showed a significant negative association of CO with muscle strength as reflected by lower HGS, whereas high BMI without CO showed a significant positive association, especially in males. The high BMI with CO and normal BMI with CO population in our study did have longer TUG, and higher prevalence of falls. In some studies, obesity is associated with higher muscle mass but poor muscle quality and function due to intramuscular fat infiltration affecting muscle strength leading to frailty, sarcopenia, increased mortality, and morbidity (38). 'Sarcopenic obesity', defined by the concurrent presence of obesity with low muscle mass and function, has been an emerging area of research in recent years where the discussion on definition, diagnostic criteria, and management continues to evolve (39). Gain in visceral fat as reflected by CO has been associated with increased fracture risk and functional decline (40). Concurrent presence of obesity, sarcopenia, osteoporosis, and frailty can accelerate the functional decline, and interventions need to address all the factors together (41). Weight reduction without protein supplementation and

resistance exercise can compromise the ability to maintain muscle mass and function leading to frailty, sarcopenia, and increased mortality (39, 42, 43). Skeletal muscle assessment and maintenance should be an integral part of all obesity clinics. Obesity has been linked to poor physical function and ADL impairment.

There was a higher prevalence of diabetes in the high BMI with CO group followed by normal BMI with CO and high BMI without CO groups. Previous studies have shown that BMI, CO, and high waist hip ratio (WHR) are all associated with diabetes (44). Interestingly, body shape index and WHR, and not high BMI, are associated with a higher incidence of stroke in diabetics (45). The prevalence of strokes was highest in our high BMI with CO group.

Our study includes population-level data from an Asian country and has shown that CO reflected by high WC is associated with negative functional and cognitive outcomes across genders. High BMI in the absence of CO may be associated with better outcomes, especially in males. This has further reinforced the need to measure WC in older adults. WC may be a better measure of obesity and is associated with many negative consequences including cognitive and functional impairment, and cardiometabolic diseases. BMI alone in older adults may not be a good reflection of obesity as losing height may over-estimate the BMI, although 85% of our population with high BMI had CO. High WC and BMI in combination may be a better prediction of obesity-related morbidity and mortality (37). WC is currently not routinely measured due to technical difficulties, but findings from our study and previous studies have highlighted that WC should be included as one of the vital signs measured in primary care, with necessary interventions put in place to screen for chronic diseases, function, frailty, and cognitive outcomes. Physical activity has been shown to reduce mortality in those with high adiposity (46, 47).

Our study has several limitations which warrant mention. We only looked at BMI and WC, but not WHR as indicator of obesity and association with negative outcomes. WHR is known to be associated with an increased cardiovascular mortality and diabetes, but its impact on cognition and function is still an evolving area of research (7, 45, 48). Risk of cognitive impairment has been shown to be higher in older adults with high WHR and BMI > 25.3 kg/m^2 (35). While we included education status where the high BMI without CO group was better educated than the normal BMI with CO group, we did not include or adjust for socio-economic status. Many studies have found that general obesity defined by BMI ≥ 30.0 kg/m^2

is associated with negative outcomes including mortality, frailty, and decline in walking speed (10, 49). However, we defined high BMI as ≥ 23.0 kg/m^2 and did not further stratify into overweight and obese groups due to the small sample size. While our study is representative of community-dwelling older adults, the sample size in both the high BMI without CO and normal BMI with CO group is relatively small. While there were significant associations with negative outcomes, it needs to be further validated with a larger sample size. In addition, self-reporting may lead to under-reporting and recall bias.

With the globally aging population and effect of the COVID-19 pandemic, the prevalence of older adults with obesity will increase. Public education should focus on measuring WC and CO rather than BMI alone in older adults, with increased emphasis on frailty and sarcopenia prevention. Further longitudinal studies are needed to validate the benefits of high BMI both in male and female and to determine the optimal cut-off for WC and BMI in predicting adverse outcomes in older adults with heterogenous functional status, across different populations and ethnicity worldwide. In addition, the impact of reducing WC on cognition and physical function needs to be further evaluated in older adults.

Conclusion

CO may be a better reflection of obesity and predictor of adverse outcomes in older adults. High BMI without CO was associated with better functional and cognitive outcomes especially in males but requires further validation. Public education should focus not on reducing weight but rather on reducing WC and building muscle strength as weight loss is associated with frailty. More prospective longitudinal studies are needed on the impact of BMI, CO alone, or in combination on intrinsic capacity, morbidity, and mortality.

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