Title: Associations between self-reported weight history and sarcopenic obesity in adults with knee osteoarthritis

Authors and Affiliations:

Godziuk, Kristine, PhD
Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, AB, Canada.
godziuk@ualberta.ca

Prado, Carla M, PhD, RD
Department of Agricultural, Food and Nutritional Science, Faculty of Agricultural, Life and Environmental Sciences, University of Alberta, Edmonton, AB, Canada.
carla.prado@ualberta.ca

Woodhouse, Linda J, PT, PhD
School of Physiotherapy and Exercise Science, Faculty of Health Sciences, Curtin University, Perth, Australia.
linda.woodhouse@curtin.edu.au

Forhan, Mary, OT, PhD
Department of Occupational Therapy, Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, AB, Canada.
forhan@ualberta.ca

Keywords: Weight history, weight cycling, sarcopenia, obesity, osteoarthritis

Running title: Weight history and sarcopenic obesity

Word count: 2237

Disclosure: All authors declare that they have no competing interests that would create a conflict of interest in connection with this manuscript. KG, CMP and MF have no disclosures; LJW has received consulting fees from Eli Lily and Scholar Rock for work unconnected to this manuscript.

Funding: Data collection for this study was supported through a PhD internship for Kristine Godziuk from Mitacs Accelerate and the Alberta Bone and Joint Health Institute (ABJHI), and seed funding from the Alberta Health Services Diabetes, Obesity and Nutrition Strategic Clinical Network.

Corresponding Author:
Kristine Godziuk
Faculty of Rehabilitation Medicine, University of Alberta
8205 – 114 Street, 2-64 Corbett Hall, Edmonton, AB, T6G 2G4
Ph: 780-492-9020, Fax: 780-492-4628, Email: godziuk@ualberta.ca

What is already known about this subject?

- Sarcopenic obesity can occur in adults with advanced knee osteoarthritis (OA), with negative implications on clinical outcomes.
- Self-reported weight history (particularly lifetime and recent weight gain trajectory, and multiple weight cycling events) have been associated with the presence of sarcopenic obesity in other clinical and community cohorts.

What are the new findings?

- Self-reported weight gain in the preceding year was associated with the presence of sarcopenic obesity in adults with advanced knee OA.
- No associations were found with weight gain in the past decade, or frequent weight cycling events during the lifespan.

How might your results change the direction of research or the focus of clinical practice?

- Discussions about recent weight trajectory may help identify individuals with knee OA who are at-risk for sarcopenic obesity. This may support future efforts to screen for this condition in clinical settings.
- Weight loss is routinely advised for individuals with obesity and knee OA, however our findings suggest that prioritizing and supporting prevention of weight gain may be more important with respect to sarcopenic obesity.

Abstract

Objective: Examine associations between self-reported weight history and sarcopenic obesity in adults with advanced knee osteoarthritis (OA).

Methods: Self-reported weight history was collected from n=151 adults (58.9% female) with knee OA and a body mass index (BMI) ≥30 kg/m^2 in a cross-sectional study. Body composition was assessed using dual-energy x-ray absorptiometry. Sarcopenic obesity was defined as appendicular skeletal muscle mass (ASM), adjusted by BMI, <0.51 kg/m^2 in females and <0.79 kg/m^2 in males; prevalence was 27.2%. Weight gain in the preceding year, weight gain ≥5% of body weight in past decade, and multiple weight cycling events in lifespan [loss of ≥10 lbs (4.5 kg) with regain ≥3 times] were examined using logistic regression (adjusted by age, sex and %fat mass), with the dependent variable of sarcopenic obesity presence.

Results: Weight gain in the preceding year was associated with sarcopenic obesity (OR 2.45, 95%CI 1.02-5.87). No associations were found with weight gain in past decade (OR 1.04, 95%CI 0.43-2.5), or weight cycling (OR 0.86, 95%CI 0.37-2.01).

Conclusions: In adults with obesity and advanced knee OA, self-reported weight gain in the preceding year was associated with sarcopenic obesity. This patient population may benefit from recommendations that prioritize prevention of weight gain.

Introduction

Sarcopenic obesity (defined as low muscle mass in the presence of higher fat mass) is gaining attention as an important health condition due to its adverse influence on patients' physical function, health-related quality of life and mortality risk[1,2]. This condition has been identified in several clinical populations (including patients with cancer[3], heart failure[4], and orthopedic conditions[5,6]) with indications that it can negatively impact treatment outcomes. Therefore, identification of individuals with, or at-risk for, sarcopenic obesity is necessary to optimize clinical care pathways. The current clinical reference standard for identification of sarcopenic obesity involves measurement of body composition compartments of muscle and fat mass using dual-energy x-ray absorptiometry (DXA)[7,8]. However, availability of DXA for body composition assessments is limited in many healthcare settings. Therefore, alternative approaches that support detection of individuals at-risk for sarcopenic obesity would be beneficial to allow earlier application of targeted strategies to maintain or improve muscle mass and physical function.

Two recent studies suggest that self-reported weight history (particularly lifetime and recent weight gain trajectory[9] and weight cycling[10]) could provide information about the risk of sarcopenic obesity. Batsis et al.[9] examined weight trajectory data from the National Health and Nutrition examination surveys (NHANES) according to the presence of low appendicular skeletal muscle mass (ASM) normalized by body mass index (BMI)[11]. They found that weight gain ≥5% in the preceding year or past decade were associated with an increased risk of low ASM/BMI [OR 1.35 (95% CI 0.99-1.87), and OR 2.03 (1.66-2.49), respectfully], suggesting that longitudinal self-reported weight changes could be used clinically to provide early indication of individuals at risk of developing low muscle mass. Alternatively, Rossi et al.[10] examined whether a reported history of multiple weight cycling could independently predict the presence of low

muscle mass in adults attending a bariatric rehabilitation centre. Similar to Batsis et al.[9], they used accepted ASM/BMI cut-points (<0.51 kg/m^2 in females and <0.79 kg/m^2 in males)[11] to discern sarcopenic obesity. They found that severe weight cycling (defined as more than six cycles of planned weight loss ≥3 kg during adulthood with subsequent involuntary weight regain) had an increased risk of sarcopenic obesity (OR 5.04, 95% CI 1.87-13.58)[10].

These findings are of interest as they suggest that self-reported weight history factors may be useful for risk stratification of sarcopenic obesity, potentially before functional decline occurs. This information could be pragmatically collected and used to discern patients with latent sarcopenic obesity in clinical settings, and support early treatment provision to maintain or increase muscle mass and physical function while reducing fat mass. However, additional investigations are needed to clarify the robustness and relevance of these findings in other clinical populations.

Therefore, the current study aimed to evaluate associations between self-reported weight history (including weight gain and weight cycling) and the presence of sarcopenic obesity (identified by low ASM/BMI) in a clinical cohort of adults with obesity and advanced knee osteoarthritis.

Methods

This study is an analysis of self-reported weight history data collected from adults with advanced knee osteoarthritis who were involved in a cross-sectional study on the prevalence and implications of sarcopenic obesity[5]. Patients were enrolled in the study from May 2017-March 2018 at an orthopedic clinic where screening was conducted for consideration of total knee arthroplasty. Inclusion criteria were a BMI ≥30 kg/m^2, no history of prior bariatric surgery or joint arthroplasty, and able to communicate and give informed written consent in English.

Patient characteristics and body composition

Age and sex were reported by patients. Height and weight were measured and BMI was calculated, as described previously[5]. Waist and hip circumference were measured over light clothing, and the average of three measures was recorded. Body composition was assessed using dual-energy x-ray absorptiometry (DXA) (GE Healthcare Lunar iDXA, analyzed with enCORE software version 16). Fat mass (FM), bone mineral concentration (BMC) and lean mass (LM) were measured. Appendicular skeletal muscle mass (ASM) was calculated as LM of arms plus legs.

Sarcopenic obesity

Sarcopenic obesity was identified by ASM adjusted by BMI (ASM/BMI), below established sex-specific cut-points of <0.51 kg/m^2 and <0.79 kg/m^2, in females and males respectively[11].

Weight history

Patients self-reported their weight history into an electronic questionnaire facilitated using data capture tools[12]. They indicated whether their primary physician had advised weight loss to help manage their knee osteoarthritis (yes or no). They were asked to categorize their weight in the preceding year as: weight stable, gained weight, or lost weight. No specific quantification of amount of weight loss or gain was collected. If patients indicated they lost weight, they further indicated if this was planned or unplanned. Patients also recalled their weight one-year prior, and ten-years prior. Weight trajectory during the past decade was defined as the difference between these two time points (weight ten-years prior minus one-year prior)[9]. Percent weight change during this trajectory was calculated as the quotient of the difference between these two time-points[9]. Differences <±5% were considered as weight stable, whereas differences >±5% were

considered as either weight gain (>+5%) or weight loss (>-5%)[9]. Information about frequency of weight loss attempts and subsequent weight regain (defined as weight cycling) over the life course was also collected by asking how many times they had lost ≥10 lbs (4.5 kg) because they were trying to lose weight. Weight cycling was categorized as: none/few (0-2 times), multiple (3-5 times), or frequent (6 or more times).

Statistical analysis

Descriptive statistics are presented as means (standard deviations) or frequency (proportion). All participants had complete data. Associations between weight history factors and sarcopenic obesity were examined using logistic regression. Separate models were built for weight cycling, weight gain (past decade) and weight gain (preceding year) as independent variables, adjusted for age, sex and percent fat mass (%FM). Sarcopenic obesity (present) was the dependent variable. Analyses were conducted using IBM SPSS Statistics v26 (IBM Corp., Armonk, NY), and p values of <0.05 were considered significant.

Results

The sample included n=151 adults (58.9% female), with a mean age 65.1±7.9 years, and mean BMI 37.1±5.5 kg/m^2. Sex-specific body composition data for this cohort has been previously published[5]. All participants met obesity criteria based on BMI (≥30 kg/m^2), waist circumference (>88 cm in females and >102 cm in males[13]) and %FM (≥35% in females and ≥25% in males[14]). Sarcopenic obesity was present in 27.2% of the sample [n=23 males (37.1% of all males) and n=18 females (20.2% of all females)]. **Table 1** provides an aggregate description of the cohort by sarcopenic obesity status, present or absent. The frequency and proportion of self-reported participant weight history responses are presented in **Table 2**. Logistic regression analyses

indicate that self-reported weight gain in preceding year was associated with the presence of sarcopenic obesity (OR 2.45, 95% CI 1.02-5.87) (**Table 3**). Conversely, neither weight gain in the past decade (OR 1.04, 95% CI 0.43-2.5), nor multiple weight cycling over the lifespan (OR 0.86, 95% CI 0.37-2.01) were associated with sarcopenic obesity. Sex was independently associated with sarcopenic obesity [OR 2.33 (95% CI 1.12-4.83) p=0.023] in our models, whereas age [OR 1.01 (95% CI 0.97-1.06) p=0.586] and %FM were not [OR 1.04 (95% CI 0.99-1.1) p=0.102].

Discussion

In this clinical sample of adults with knee osteoarthritis (OA) and obesity, only self-reported weight gain in the preceding year was associated with the presence of sarcopenic obesity (OR 2.13, 95% CI 1.02-4.43). This association remained relevant when controlling for age, sex and %FM (OR 2.45, 95% CI 1.02-5.87). In contrast, self-reported multiple weight cycling and weight gain over the past decade were not associated with sarcopenic obesity in this cohort.

These findings suggest that self-reported weight gain in the preceding year may be most important to consider for the presence of sarcopenic obesity in adults with knee OA. This concurs with the results from Batsis et al.[9] which showed an association between low ASM/BMI and prior-year weight gain in their NHANES population-representative sample. While they also reported an association with past decade weight gain, that was not found in our cohort. Weight gained in middle-age years and later is primarily comprised of increases in fat mass[15]. This gain of fat mass can alter the ratio of fat to muscle mass compartments that is relevant for ASM/BMI definitions of sarcopenic obesity, and development of mobility disability[15]. Concurrently, increased fat mass can drive inflammatory pathways that accelerate decline in muscle mass[16]. This shifting ratio of body composition compartments may be even more relevant when knee OA

is present, as it can independently influence muscle loss through OA symptom-associated disuse and inactivity.

Interestingly, a higher proportion of individuals with sarcopenic obesity in our sample reported being advised by their primary physician to lose weight to help manage their OA (73.2% vs 54.5% without sarcopenic obesity, Table 2). This is contrary to what might be expected considering the relationship found with preceding year weight gain. However it aligns with population findings from North America that show increasing trends in measured body weight and BMI, despite higher proportions of individuals self-reporting attempted weight loss[17]. This may be an indication of the challenges of maintaining long-term weight loss using behavioural approaches[18,19].

Our findings suggest that advice for this clinical population should prioritize and support prevention of weight gain. This is contrary to clinical practice guidelines for knee OA which predominantly recommend weight loss[20–22]. Weight gain prevention may be more practical and achievable, particularly as this clinical population is at heightened risk for weight gain and muscle loss due to inactivity and disuse relative to OA-associated pain and stiffness. Further, weight loss recommendations could potentially have negative implications if they prompt individuals to use caloric restriction or unsupervised fad dieting approaches[23]. As a result, muscle mass is lost alongside fat mass (accounting for around 30% of weight loss), however any weight regained primarily consists of fat mass[24]. This could paradoxically further disrupt the ratio of muscle mass to fat mass, resulting in the development of sarcopenic obesity. Treatment approaches that enable fat loss while maintaining or increasing muscle mass (through a combination of resistance training and adequate protein intake)[25] may be beneficial, however their effectiveness in clinical cohorts with knee OA has not been established.

Although we were unable to explore the specific composition of weight change in the prior year with the current data, longitudinal changes are of interest. It is unknown if sarcopenic obesity developed within the prior year, or if it was already present. Speculatively, individuals may have lost and regained weight during this time period, resulting in a net weight gain at the end of the year. Alternatively, they may have simply gained weight. In either scenario, it is projected that fat mass increased whereas muscle mass decreased (through disuse or inactivity related to OA-symptoms, as a result of ongoing aging-related declines, or lost as a result of caloric restriction if weight loss was attempted unsuccessfully). Additionally, there is also the potential that sarcopenic obesity predisposes an individual to weight gain as a result of metabolic rate declines linked with low muscle mass[26]. There is a need for further exploration in this area.

Our results differed from Rossi et al.[10] as we found no association between weight cycling and sarcopenic obesity. This may have been a result of cohort differences, as their sample was younger and without knee OA, or due to differences in the weight cycling definitions used. It may also be related to their considerably higher prevalence of sarcopenic obesity (61.8% in their sample, compared to 27.2% in our cohort, akin to the 23.0% reported in Batsis et al.[9]). Notably, the literature is unclear whether repeated weight-loss-and-regain cycles consistently result in a cumulative net loss of muscle mass[27,28].

Sex was independently associated with sarcopenic obesity in our models, whereas age was not. Sarcopenic obesity occurs across age-categories. Although our cohort size prevented examination of sex-specific models, future investigations should consider stratification by sex as many relevant factors have known sex differences (including body composition changes with aging[29], and in response to weight loss and regain[27]). Sex differences in the pathogenesis of sarcopenic obesity[30,31] are likely, as suggested by the body composition values in our cohort.

Absolute fat mass appeared higher in males with sarcopenic obesity (compared to males without this condition), but this disparity was not present in females. This could suggest that preventing fat mass accretion is more important in males relative to sarcopenic obesity, although further investigation is necessary.

Strengths and limitations

To our knowledge, this is the first study in a clinical knee OA population to examine associations between self-reported weight history and sarcopenic obesity. It is recognized that some study limitations are present, including the cross-sectional approach and self-reported data, with implications for bias. However self-recalled body weight up to ten years prior has been shown to be acceptably accurate in comparison to measured weight in adults with obesity[32]. Our smaller cohort size prevented independent comparisons of all weight history sub-categories (i.e. weight lost, with weight stable as reference). Further, our analyses may be underpowered due to the limited sample and outcome prevalence (low ASM/BMI) of 27.2%. Confirmation of these associations in larger cohorts will be important. ASM/BMI accepted cut-points were used for identification of sarcopenic obesity in this study (similar to comparison studies[9,10]), however results may differ if other diagnostic criteria were used. A consensus definition is still in development[8]. We did not collect information on quantification of weight loss or gain in the preceding year, so it is unknown if certain thresholds of weight gain would alter the relationships in our results. The unplanned weight loss reported in a small subgroup of our participants would be interesting to examine further in a larger sample, as it could signal the presence of other conditions (e.g. cancer) that are influencing body composition. Finally, we did not collect any data on nutrition or physical activity behaviours, which may have influenced the associations in

our analysis. These lifestyle factors have implications on body composition and should be considered in future studies.

Conclusions

In adults with obesity and advanced knee OA, self-reported weight gain in the preceding year was associated with the presence of sarcopenic obesity. Although we were unable to assess whether weight gain directly influenced the development, progression or severity of this condition, our findings suggest that attention to recent weight trajectory may be important. This patient population may benefit from additional clinical support to prevent weight gain, in order to decrease the risk and negative implication of sarcopenic obesity.

Table 1. Patient characteristics (n=151), by sarcopenic obesity present* or absent (non-sarcopenic with obesity)

	Sarcopenic obesity n=41		**Non-sarcopenic with obesity n=110**	
	Females n=18 (43.9%)	**Males** n=23 (56.1%)	**Females** n=71 (64.5%)	**Males** n=39 (35.5%)
Age (years)	65.8 (8.3)	65.6 (6.7)	64.6 (8.6)	65.4 (7.4)
Height (cm)	154.1 (5.5)	168.3 (5.6)	162.6 (5.2)	178.2 (6.3)
Weight (kg)	93.2 (14.5)	109.8 (21.4)	99.0 (16.1)	109.9 (15.2)
BMI (kg/m^2)	39.4 (5.8)	38.6 (6.7)	37.4 (5.5)	34.5 (3.8)
Waist circumference (cm)	119.7 (11.4)	127.8 (13.8)	119.2 (12.3)	121.2 (8.8)
Hip circumference (cm)	129.5 (11.3)	123.3 (13.5)	130.2 (11.9)	119.7 (8.8)
FM (kg)	49.9 (10.7)	47.5 (12.6)	49.4 (11.1)	41.6 (9.8)
FM (%)	53.2 (3.4)	42.8 (4.7)	49.5 (4.2)	37.5 (4.4)
LM (kg)	40.5 (4.2)	58.2 (8.8)	47.2 (6.7)	64.8 (6.7)
LM (%)	43.8 (3.3)	53.6 (5.0)	48.0 (4.0)	59.4 (4.2)
ASM (kg)	18.5 (2.5)	27.5 (4.8)	22.4 (3.8)	30.9 (3.7)
ASMI (kg/m^2)	7.8 (1.04)	9.7 (1.54)	8.47 (1.36)	9.73 (0.93)
ASM/BMI (kg/m^2)	0.47 (0.04)	0.71 (0.05)	0.60 (0.06)	0.90 (0.08)

Values presented are mean (standard deviation)

* defined as ASM/BMI <0.51 kg/m^2 in females, and <0.79 kg/m^2 in males[11]

ASM = appendicular skeletal muscle mass, ASMI = ASM Index (ASM/$height^2$), BMI = body mass index, FM = fat mass, LM = lean mass

Table 2. Frequency and proportion [n (%)] of self-reported weight history in study cohort (n=151) by sex and sarcopenic obesity status

Weight History	Sex		Sarcopenic Obesity	
	Female n=89	**Male n=62**	**Present* n=41**	**Absent n=110**
Weight loss advised to manage knee OA:				
Yes	56 (62.9)	34 (54.8)	30 (73.2)	60 (54.5)
Weight cycling† in lifespan:				
None/few weight loss attempts (0-2x)	32 (36.0)	34 (54.8)	19 (46.3)	47 (42.7)
Multiple weight loss attempts (3-5x)	26 (29.2)	20 (32.3)	13 (31.7)	33 (30.0)
Frequent weight loss attempts (≥6x)	31 (34.8)	8 (12.9)	9 (22.0)	30 (27.3)
Weight trajectory in past decade:				
Stable (< ±5% change)	29 (32.6)	26 (41.9)	13 (31.7)	42 (38.2)
Gaining (> +5% change)	51 (57.3)	28 (45.2)	24 (58.5)	55 (50.0)
Losing (> -5% change)	9 (10.1)	8 (12.9)	4 (9.8)	13 (11.8)
Weight change$ in preceding year:				
Weight stable	27 (30.3)	22 (35.5)	12 (29.3)	37 (33.6)
Weight gained	29 (32.6)	25 (40.3)	20 (48.8)	34 (30.9)
Weight lost	33 (37.1)	15 (24.2)	9 (21.9)	39 (35.5)
Unplanned	5 (15.2)	5 (33.3)	2 (22.2)	8 (20.5)
Planned	28 (84.8)	10 (66.7)	7 (77.7)	31 (79.5)

*defined as ASM/BMI <0.51 kg/m^2 in females, and <0.79 kg/m^2 in males[11]

†loss of ≥10 lbs (4.5kg) with subsequent regain

$no specific quantification of weight gain or loss

OA = osteoarthritis

Table 3. Logistic regression analyses between self-reported weight history and the presence of sarcopenic obesity

3a. Weight cycling

	Model 1 OR (95% CI)	*p-value*	**Model 2** OR (95% CI)	*p-value*	**Model 3** OR (95% CI)	*p-value*	**Model 4** OR (95% CI)	*p-value*
Weight cycling ≥3x[†]	0.86 (0.42-1.78)	*0.691*	0.88 (0.43-1.82)	*0.734*	1.03 (0.49-2.19)	*0.935*	0.86 (0.37-2.01)	*0.735*
Age			1.01 (0.97-1.06)	*0.614*	1.01 (0.96-1.06)	*0.630*	1.03 (0.97-1.08)	*0.327*
Sex					2.33 (1.12-4.9)	*0.026*	37.82 (8.72-163.92)	*<0.001*
%FM							1.28 (1.16-1.42)	*<0.001*

3b. Weight gaining past decade

	Model 1 OR (95% CI)	*p-value*	**Model 2** OR (95% CI)	*p-value*	**Model 3** OR (95% CI)	*p-value*	**Model 4** OR (95% CI)	*p-value*
Weight gaining past decade[ǂ]	1.31 (0.64-2.71)	*0.462*	1.39 (0.66-2.94)	*0.382*	1.59 (0.73-3.44)	*0.243*	1.04 (0.43-2.5)	*0.938*
Age			1.02 (0.97-1.07)	*0.471*	1.02 (0.97-1.07)	*0.457*	1.03 (0.97-1.09)	*0.306*
Sex					2.46 (1.17-5.18)	*0.018*	37.59 (8.71-162.2)	*<0.001*
%FM							1.28 (1.15-1.42)	*<0.001*

3c. Weight gained preceding year

	Model 1 OR (95% CI)	*p-value*	**Model 2** OR (95% CI)	*p-value*	**Model 3** OR (95% CI)	*p-value*	**Model 4** OR (95% CI)	*p-value*
Weight gained preceding year[ǂ]	2.13 (1.02-4.43)	*0.044*	2.2 (1.05-4.61)	*0.037*	2.2 (0.99-4.45)	*0.054*	2.45 (1.02-5.87)	*0.044*
Age			1.02 (0.97-1.07)	*0.451*	1.02 (0.97-1.07)	*0.506*	1.04 (0.98-1.09)	*0.203*
Sex					2.2 (1.06-4.66)	*0.035*	35.73 (8.24-154.9)	*<0.001*
%FM							1.28 (1.16-1.42)	*<0.001*

[†]none/few weight cycling events as reference

[ǂ]weight stable and weight lost/losing as reference

CI = confidence interval, OR = odds ratio, %FM = percent fat mass

References

1. Van Aller C, Lara J, Stephan BCM, Donini LM, Heymsfield S, Katzmarzyk PT, et al. Sarcopenic obesity and overall mortality: Results from the application of novel models of body composition phenotypes to the National Health and Nutrition Examination Survey 1999–2004. *Clin Nutr*. 2018. doi:10.1016/j.clnu.2018.01.022

2. Prado CM, Purcell SA, Alish C, Pereira SL, Nicolaas E, Heyland DK, et al. Implications of low muscle mass across the continuum of care: a narrative review. *Ann Med*. 2018. doi:10.1080/07853890.2018.1511918

3. Carneiro IP, Mazurak VC, Prado CM. Clinical implications of sarcopenic obesity in cancer. *Curr Oncol Rep*. 2016;18(10). doi:10.1007/s11912-016-0546-5

4. Carbone S, Billingsley HE, Rodriguez-Miguelez P, Kirkman DL, Garten R, Franco RL, et al. Lean Mass Abnormalities in Heart Failure: The Role of Sarcopenia, Sarcopenic Obesity, and Cachexia. *Curr Probl Cardiol*. 2019. doi:10.1016/j.cpcardiol.2019.03.006

5. Godziuk K, Prado CM, Woodhouse LJ, Forhan M. Prevalence of sarcopenic obesity in adults with end-stage knee osteoarthritis. *Osteoarthr Cartil*. 2019;27(12):1735-1745. doi:10.1016/j.joca.2019.05.026

6. Ji HM, Han J, Jin DS, Suh H, Chung YS, Won YY. Sarcopenia and sarcopenic obesity in patients undergoing orthopedic surgery. *Clin Orthop Surg*. 2016;8(2):194-202. doi:10.4055/cios.2016.8.2.194

7. Buckinx F, Landi F, Cesari M, Fielding RA, Visser M, Engelke K, et al. Pitfalls in the measurement of muscle mass: a need for a reference standard. *J Cachexia Sarcopenia Muscle*. 2018;9:269-278. doi:10.1002/jcsm.12268

8. Donini LM, Busetto L, Bauer JM, Bischoff S, Boirie Y, Cederholm T, et al. Critical appraisal of definitions and diagnostic criteria for sarcopenic obesity based on a systematic review. *Clin Nutr*. 2020;39(8):2368-2388. doi:10.1016/j.clnu.2019.11.024

9. Batsis JA, Petersen CL, Crow RS, Cook SB, Stevens CJ, Seo LM, et al. Weight change and risk of the foundation of National Institute of Health Sarcopenia-defined low lean mass: Data from the National Health and Nutrition examination surveys 1999-2004. *Clin Nutr*. 2019. doi:10.1016/j.clnu.2019.10.032

10. Rossi AP, Rubele S, Calugi S, Caliari C, Pedelini F, Soave F, et al. Weight Cycling as a Risk Factor for Low Muscle Mass and Strength in a Population of Males and Females with Obesity. *Obesity*. 2019;27(7):1068-1075. doi:10.1002/oby.22493

11. Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, et al. The FNIH sarcopenia project: Rationale, study description, conference recommendations, and final estimates. *Journals Gerontol A Biol Sci Med Sci*. 2014;69(5):547-558. doi:10.1093/gerona/glu010

12. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research Electronic Data Capture (REDCap) - A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inf*. 2009;42(2):377-381.

doi:10.1016/j.jbi.2008.08.010.

13. Levine ME, Crimmins EM. The impact of insulin resistance and inflammation on the association between sarcopenic obesity and physical functioning. *Obesity (Silver Spring)*. 2012;20(10):2101-2106. doi:10.1038/oby.2012.20

14. Batsis JA, Mackenzie TA, Lopez-Jimenez F, Bartels SJ. Sarcopenia, sarcopenic obesity, and functional impairments in older adults: National Health and Nutrition Examination Surveys 1999-2004. *Nutr Res*. 2015;35(12):1031-1039. doi:10.1016/j.nutres.2015.09.003

15. Vincent HK, Vincent KR, Lamb KM. Obesity and mobility disability in the older adult. *Obes Rev*. 2010;11(8):568-579. doi:10.1111/j.1467-789X.2009.00703.x

16. Godziuk K, Prado CM, Woodhouse LJ, Forhan M. The impact of sarcopenic obesity on knee and hip osteoarthritis: a scoping review. *BMC Musculoskelet Disord*. 2018. doi:10.1186/s12891-018-2175-7

17. Han L, You D, Zeng F, Feng X, Astell-Burt T, Duan S, et al. Trends in Self-perceived Weight Status, Weight Loss Attempts, and Weight Loss Strategies Among Adults in the United States, 1999-2006. *JAMA Netw Open*. 2019;2(11):e1915219. doi:10.1001/jamanetworkopen.2019.15219

18. Dombrowski SU, Knittle K, Avenell A, Araújo-Soares V, Sniehotta FF. Long term maintenance of weight loss with non-surgical interventions in obese adults: systematic review and meta-analyses of randomised controlled trials. *BMJ*. 2014;348(May):g2646. doi:10.1136/bmj.g2646

19. Christensen P, Henriksen M, Bartels EM, Leeds AR, Larsen TM, Gudbergsen H, et al. Long-term weight-loss maintenance in obese patients with knee osteoarthritis: a randomized trial. *Am J Clin Nutr*. 2017;106:755-763.

20. Kolasinski SL, Neogi T, Hochberg MC, Oatis C, Guyatt G, Block J, et al. 2019 American College of Rheumatology/Arthritis Foundation Guideline for the Management of Osteoarthritis of the Hand, Hip and Knee. *Arthritis Rheumatol*. 2020. doi:10.1002/art.41142

21. McAlindon TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, Bierma-Zeinstra SM, et al. OARSI guidelines for the non-surgical management of knee osteoarthritis. *Osteoarthr Cartil*. 2014;22(3):363-388. doi:10.1016/j.joca.2014.01.003

22. Jevsevar DS, Manner PA, Bozic KJ, Goldberg MJ, Martin WR, Cummins DS, et al. The American Academy of Orthopaedic Surgeons evidence based guideline on treatment of osteoarthritis of the knee, 2nd edition. *J Bone Jt Surg*. 2013:1885-1886.

23. Weinheimer EM, Sands LP, Campbellnure WW. A systematic review of the separate and combined effects of energy restriction and exercise on fat-free mass in middle-aged and older adults: Implications for sarcopenic obesity. *Nutr Rev*. 2010;68(7):375-388. doi:10.1111/j.1753-4887.2010.00298.x

24. Beavers KM, Lyles MF, Davis CC, Wang X, Beavers DP, Nicklas BJ. Is lost lean mass from intentional weight loss recovered during weight regain in postmenopausal women? *Am J Clin Nutr*. 2011;94(3):767-774. doi:10.3945/ajcn.110.004895

25. Jo E, Worts PR, Elam ML, Frost A, Khamoui A V, Kim D, et al. Resistance training during a 12-week protein supplemented VLCD treatment enhances weight-loss outcomes in obese patients. *Clin Nutr*. 2019;38(1):372-382. doi:10.1016/j.clnu.2017.12.015

26. Sakuma K, Yamaguchi A. Sarcopenic obesity and endocrinal adaptation with age. *Int J Endocrinol*. 2013;2013. doi:10.1155/2013/204164

27. Lee JS, Visser M, Tylavsky FA, Kritchevsky SB, Schwartz A V, Sahyoun N, et al. Weight loss and regain and effects on body composition: the Health, Aging, and Body Composition Study. *J Gerontol A Biol Sci Med Sci*. 2010;65(1):78-83. doi:10.1093/gerona/glp042

28. Bosy-Westphal A, Muller MJ. Measuring the impact of weight cycling on body composition: a methodological challenge. *Clin Nutr*. 2014;17(5):396-400. doi:10.1097/MCO.0000000000000092

29. Janssen I, Heymsfield SB, Wang Z, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J Appl Physiol*. 2000;89(1):81-88. http://jap.physiology.org/content/89/1/81%5Cnhttp://jap.physiology.org/content/89/1/81.full.pdf%5Cnhttp://www.ncbi.nlm.nih.gov/pubmed/10904038.

30. Barazzoni R, Bischoff S, Boirie Y, Busetto L, Cederholm T, Dicker D, et al. Sarcopenic obesity: time to meet the challenge. *Eur J Obes*. 2018:294-305. doi:10.1159/000490361

31. Zamboni M, Mazzali G, Fantin F, Rossi A, Di Francesco V. Sarcopenic obesity: A new category of obesity in the elderly. *Nutr Metab Cardiovasc Dis*. 2008;18(5):388-395. doi:10.1016/j.numecd.2007.10.002

32. Olivarius N, Andreasen A, Løken J. Accuracy of 1-, 5- and 10-year body weight recall given in a standard questionnaire. *Int J Obes*. 1997;21:67-71.