Comparison of the gluteus medius strength between obese and eutrophic individuals: a cross-sectional study

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Research article

Keywords: Obesity, Hip, Muscle weakness

Posted Date: June 3rd, 2020

DOI: https://doi.org/10.21203/rs.2.24323/v2

Abstract

Background: The hip abductor muscles play an important role in stabilizing the pelvis during gait, with its main function being performed by the gluteus medius. Gluteus medius insufficiency is associated with biomechanical alterations and musculoskeletal disorders. Due to being overweight and a possible muscle mass decrease, maintaining the abductor muscular function can be a great challenge for the obese. However, it is still unclear whether the musculature of obese individuals manages to compensate for these alterations. Therefore, the aim of this study was to compare the gluteus medius strength between obese and normal weight individuals using a digital hand-held dynamometer.

Methods: Twenty-five obese (BMI > 35 kg / m^2) participated in the study, being matched in gender, age, and height with normal weight individuals. The gluteus medius strength was measured by a single examiner using a belt-stabilized hand-held digital dynamometer on the knee of individuals positioned in lateral decubitus. Three measurements were recorded with rest intervals, considering only the highest value measured for each limb for analysis. The difference between pairs was calculated and the data distribution pattern was assessed using the Shapiro-Wilk test ($p < 0.05$), and the matrices of the variables were standardized and analyzed using the principal component analysis (PCA).

Results: For the strength variables (Newtons) on both sides, no statistical differences were detected between the groups ($p > 0.05$). However, statistical differences were detected in these variables between the groups ($p < 0.05$) when normalizing the measurements in relation to individuals' weights (Newtons / kilograms). The PCA indicates that both strength in absolute values and normalized by weight are reduced in obese individuals.

Conclusions: These findings indicate that obese individuals have the same or lower strength (PCA) to move more mass, which may suggest a relative weakness that induces functional limitation.

Trial registration: The study was approved by the UNIOESTE Human Research Ethics Committee (#1.180.202) in July 2015.

Background

Hip abductor muscles play an important role in stabilizing the pelvis during gait, which allows effective body maintenance and a proper lower limb mobility [1]. This group of muscles includes the gluteus medius, gluteus minimus, and tensor fasciae latae. They collaborate for the normal contact of forces within the hip joint, in association with the iliopsoas and hamstrings [2]. The maximum peak contact force in this joint can reach four times the body weight [3], being higher when there are gait disorders [4]. The main hip abductor muscle is the gluteus medius, being the major contributor to upper and medial components of joint forces [2] and the primary contributor to the mediolateral balance of the body [5].

The magnitude of the abductor musculature force required to stabilize the pelvic balance is approximately 2.5 times the body weight [6], confirmed by *in vivo* studies [7]. Thus, the strength combination of the abductor muscles must be a multiple of the weight. Until there is enough strength to support the weight, the gait will be normal and the joint will work properly. If weight overload or muscle weakness occurs, an adaptation of the upper body will be triggered in an attempt to bring the center of gravity closer to the center of hip rotation. Failure of the gluteal musculature establishes a pathological gait pattern, defined as Trendelenburg gait [8], as well as reduced abduction strength, tendency to external rotation, and internal rotation weakness of the lower limb [9].

When a three-dimensional gait analysis of obese individuals is performed, alterations with greater hip adduction are observed during the terminal stance and pre-balance phases, associated with a marked ankle eversion [10]. There is clearly an imbalance, with a negative influence on gait parameters [11]. Maintaining the strength of the gluteal musculature can be a huge challenge for these individuals. These alterations produce anteroposterior and mediolateral instability of the upper body, with functional limitation and predisposition to injuries [12-14]. Gluteus medius muscle atrophy increases with advancing age, which can contribute to falls and hip fractures [15].

Obese people still suffer from the metabolic effects of adipose tissue on the muscular system. The decrease in anabolic hormones, such as growth hormone [16], and the increase in proinflammatory cytokines alter muscle metabolism. Both act on amino acid balance, neuromuscular activation, and signaling pathways in the caspase cascade [16-19]. Finally, the decrease in muscle mass establishes a condition called sarcopenic obesity [16], in which the inflammatory cytokines produced by visceral fat are able to alter muscle metabolism and trigger a vicious cycle that maintains degeneration and reduces skeletal muscle quality [20-22].

The analysis of gluteus medius strength in obese individuals is very important for clinical practice. The weakness of this muscle is associated not only with biomechanical changes, but also with musculoskeletal system disorders, such as hip arthrosis, lower back pain, knee arthrosis, and patellofemoral syndrome [23-29].

However, measuring the strength of hip muscles can be a difficult task. In this sense, several limitations are reported regarding its execution, especially related to the restricted access to precision equipment, difficulties in promoting a good positioning of the patient, variations in the support area for placing the device, possibility of patient movement, and inconstancy in the verbal stimulus intensity [31]. Manual muscle testing is the most used method for this purpose, since it is easy, quick to perform, free of charge, and does not require equipment [32]. Nevertheless, as this test is subjective and descriptive, it presents low reliability and frequently overestimates the measured strength. The isokinetic dynamometer is the reference method for other instruments that measure strength, and is the practical standard for muscle strength assessment [33]. Examining the cost of an isokinetic testing device and difficulties of routine clinical testing, there is evidence that supports the clinical use of the hand-held dynamometer [34]. It measures strength in an objective, precise, and sensitive way [35]. The hand-held dynamometer is a validating method when its stabilization is performed with a belt, and although they did not agree with those from the isokinetic dynamometer, the values are correlated for the hip-muscle groups [36].

The aim of this study was to measure the strength of abductor muscles, especially the gluteus medius, using a digital hand-held dynamometer to compare two groups of matched individuals: obese and eutrophic individuals.

Methods

The present study is observational, quantitative, analytical, and cross-sectional. The UNIOESTE Human Research Ethics Committee (#1.180.202) approved it in July 2015. Patients delivered written formal consent according to the rules of the ethics committee.

Obese individuals who were beginning ambulatory follow-up at the Obesity and Bariatric Surgery Service of the Western Paraná University Hospital (Cascavel, Paraná, Brazil) were included in the study. These individuals were of both genders, from 20 to 60 years old, with grade II and III obesity, characterized by a body mass index (BMI) above 35 kg / m^2 [37,38]. Exclusion criteria were pregnancy, orthopedic disease of the lower limbs, locomotor system pain or sequelae, paresthesia or weakness in the lower limbs, orthostatic or walking pain, heart disease, or other diseases with restricted functional capacity.

For comparison (control group), a normal weight sample was formed, with a BMI below 24.9 kg / m^2, a value considered normal, paired by similarity with obese individuals in relation to gender, age and height.

For the calculation of the sample, a large effect size (0.8) was assumed, due to the homogenization of the group of patients from the Obesity and Bariatric Surgery Service of HUOP, as well as a type I error equivalent to 0.05 and a power of analysis in a t-Student distribution tests equivalent to 0.80. From these parameters, a total number equal to 54 was defined.

A single examiner evaluated participants, in an attempt to avoid analysis bias between observers. Measurements of weight (kilograms, kg) and height (meters, m) were performed.

All subjects eligible for the research were evaluated for exclusion criteria through clinical history and targeted physical examination. Individuals with pregnancy, orthopedic disease of the lower limbs, pain or sequelae in the locomotor system, self-reported paresthesia or weakness in the lower limbs, orthostatic or walking pain, heart disease or other disease with restricted functional capacity were excluded.

The physical screening examination included assessment of sensory disturbance, passive leg elevation and assessment of hip joint pain after flexion and internal rotation and knee flexion and extension. Individuals who presented any changes with signs suggestive of pathology related to impairment of the locomotor system were excluded.

The gluteus medius strength was measured using a hand-held digital dynamometer (MICROFET2, Draper, USA), a device with high reliability in test-retest studies [31]. The device was positioned 5 cm proximal to the knee joint line; a technique adapted from Hislop and Montgomery [38-41]. The participant was positioned in lateral decubitus with a knee pad to avoid adduction, with slightly extended hips and anterior inclination of the pelvis, in an attempt to measure strength components predominantly related to the gluteus medius (Fig. 1). Upper limbs remain at rest to avoid assistance during strength. The dynamometer was attached to the stretcher by using a rigid band, without the need for strength against resistance on the part of the examiner. Participants were verbally asked to apply their maximum force against the device for 5 seconds, and after a 30-second interval, a new request occurred. Three measurements were made and only the highest value measured was considered for the study. After the analysis, the participant was repositioned for the measurement of the contralateral gluteus medius. The right side was always tested first.

Statistical analysis

The intra-class correlation coefficient (ICC) was calculated to assess the reproducibility of the evaluator's measurements. A pilot study was performed to randomly evaluate the strength of both right (RGM) and left (LGM) gluteus medius muscles of six individuals. A homogeneity of the measures was observed with an ICC value for the right and left sides equivalent to 0.9675 and 0.9288, respectively.

Data were tabulated in the Microsoft Excel 2013® program. Pairing was performed between groups of the variables gender, age, and height by similarity. The difference between pairs was calculated and the data distribution pattern was assessed using the Shapiro-Wilk test. The comparison between pairs was performed using the paired-samples t-test, since all variables were normally distributed. The statistical tests were performed using the R Core Team program (R Core Team, 2018) considering a significance level of 0.05.

Then, matrices of the variables were standardized and analyzed using the principal component analysis (PCA). In the PCA, the factor loads are defined as the correlations of each variable with the factor composition, where the factor is a new variable defined by the set of factor loads. This analysis did not consider the pairing, but the subdivision of two large groups, in an attempt to differentiate them. The factorial loads resulting from the main components were evaluated for their significance using the independent-samples t-test.

Results

After assessing the reliability of the measurements, 95 individuals were examined: 35 obese and 60 eutrophics. Of these, 8 individuals from the obese group and 3 individuals from the eutrophic group did not meet the selection criteria and were excluded. Two obese individuals were also excluded due to their short stature, which made it difficult to correlate their findings with eutrophic individuals. At the end, 25 control-obese pairs were formed, matched by gender correspondence and similarity of age and height. Thus, 32 eutrophic participants were excluded, since they did not match the equivalence parameters (Fig. 2).

Fifty individuals were analyzed, being 4 (8%) male and 46 (92%) female (Additional supporting files). The variables of gender, age, and height were considered statistically equivalent between obese and control groups (p > 0.05). Weight and BMI variables showed statistically significant difference between pairs ($p < 0.0001$; Table 1).

Table 1. Descriptive data of paired pairs, regarding age, height, weight, and BMI. P-value of the paired-samples t-test.

Variable	Group	Minimum	Maximum	Mean	Standard deviation	P-value
Age	Obese	20.000	60.000	43.600	9.785	0.407
	Control	23.000	57.000	42.880	10.647	
Height	Obese	1.500	1.930	1.600	0.091	0.729
	Control	1.480	1.900	1.599	0.090	
Weight	Obese	89.000	165.000	114.600	19.111	<0.0001*
	Control	45.000	80.000	58.068	8.825	
BMI	Obese	36.616	56.008	44.604	5.126	<0.0001*
	Control	17.360	24.948	22.629	2.032	

For the strength variables (N) of the RGM and LGM, no statistical differences were detected between groups ($p > 0.05$). However, when normalizing measurements in relation to individuals' weights (N/Kg), statistical differences were detected in these to variables between groups ($p < 0.05$) (Table 2, Fig. 3).

Table 2. Descriptive data of strength variables for RGM and LGM with absolute and normalized values in relation to weight. P-value of the paired-samples t-test.

		Control	Obese	P-value
Strength (N)	RGM	292.0 ± 94.5	256.2 ± 104.2	0.149
	LGM	290.7 ± 76.6	261.1 ± 118.0	0.231
Strength / Weight (N / Kg)	RGM	51.5 ± 15.6	22.7 ± 8.0	<0.0001
	LGM	51.8 ± 15.0	23.1 ± 9.1	<0.0001

Considering only the variables normalized by weight of the analyzed individuals, from the multivariate assessment, the separation of the two groups was verified: control and obese. In this study, pairing was not considered, only the division of two samples in relation to force variable, in an attempt to differentiate them. The first main component was defined as the variation of the strength values of RGM and LGM in relation to weight (in N / Kg) (Eigenvalue = 3.03; Variability =75.67%), and being directly related to the separation of the two groups analyzed. The second main component was defined by the muscle force of RGM and LGM in absolute values (in N), also being directly related (Eigenvalue = 0.72; Variability = 18.04%; Fig. 4).

The factor loads of the main component 1, which represents the variation of muscle forces, in N / Kg, showed significant differences between pairs ($t = 5.14$; $p < 0.0001$; Fig. 5a), indicating that RGM and LGM were higher in eutrophic individuals in relation to weight (in N / Kg). The factor loads of the main component 2 also showed significant differences between groups ($t = -8.63$; $p < 0.0001$), indicating that RGM and LGM, in N, tend to be reduced in obese individuals (Fig. 5b).

Discussion

In the present study, obese individuals did not present a statistically significant difference in the gluteus medius strength, compared to non-obese individuals ($p > 0.05$). However, when these values were normalized in relation to body weight, there was a significant difference ($p < 0.05$) between groups, which indicates that obese individuals have a relative gluteus medius weakness, when compared to normal weight individuals.

The absolute strength values were 292.0 N for RGM, and 290.7 N for LGM in the control group. In the obese group, the values were 256.2 N and 261.1 N, respectively. In a literature review, Benfica et al. [42] describes hip abductor muscle strength values, in individuals between 50 and 59 years old, as being 208.12 N for dominant limb and 203.27 N for non-dominant limb in women, and 305.97 N for dominant limb and 298.49 N for non-dominant limb in men. In the present study, this variation in the measurements can be explained by the age differences between the analyzed samples, gender variations, and differences related to the measurement technique. The age range of the participants (from 20 to 60 years old) was chosen since it constitutes an economically active group, in which any movement disorder can cause great functional and work impact. Also, people over 60 may have reduced muscle mass and function [43]. It is worth noting that the sample used in the present study consisted predominantly of women (92%) for reasons of convenience, and that the abductor muscle strength varies between genders. Women have lower abductor muscle strength, which corresponds to a greater risk of developing musculoskeletal pathologies [44].

Some authors suggest that the antigravity muscles of obese individuals have greater absolute force [45-48]. Increased muscle strength is a beneficial adaptation to obesity, with excess body weight acting as a chronic training stimulus for daily activities [48]. Several studies report increased knee extension strength in obese individuals, with values varying from 10 to 30% higher when compared to normal weight individuals [49]. Due to gait changes, obesity can cause mechanical adaptations that favor the use of the strongest muscles and minimize the use of the weakest muscles. Gait analysis in obese individuals shows a shorter stride length with a strategy of higher quadriceps overload and decreased hamstring activation [10,50].

Regarding the gluteus medius, Lerner et al. [13] reported that obese individuals have greater absolute strength during gait and correlated this with increased BMI. This data was not confirmed by the gluteus medius strength analysis performed in the present study, since there was no difference in the isometric strength values between groups tested ($p > 0.05$). Apparently, obesity results in larger and lower quality muscles, which have the same absolute strength and power as smaller muscles in thin individuals [51]. Analysis using nuclear magnetic resonance suggests that the gluteal musculature presents an increase in fat infiltrate with an increase in BMI [52]. Although obesity increases muscle mass in a short term in young individuals, lipid infiltration in skeletal muscle can reduce the incorporation of amino acids into muscle proteins in the course of time, with a decrease in total muscle mass [20]. Possibly, the long-term effect of obesity on muscle tissue overlaps this weight stimulus on antigravity muscles and culminates in muscle loss over the years [18].

Even though they seem to have greater absolute strength, obese individuals have less relative strength in some muscles, such as the quadriceps [53,54]. Lafortuna et al. [55] also corroborate these data when they evaluated the lower limb muscle strength through leg press exercise. Compared with normal weight individuals, obese individuals were stronger, but when the values were related to their muscle mass, this difference disappeared. When Lerner et al. [13] normalized the strength of gluteal musculature by weight, there was no relevant difference between obese and normal weight groups. Regarding muscle mass, they also reported that obese individuals required greater strength of gluteal musculature for a normal gait. This fact is relevant, since it suggests that obese individuals need greater strength in this muscle group, becoming more susceptible to fatigue. Thus, it is expected that overweight individuals have greater muscle strength to maintain proper body balance while standing or walking. This fact was not proven in the present study. When normalized in relation to body weight, obese individuals had relative weakness of gluteus medius musculatures ($p < 0.05$). It can be concluded that using the strength variable alone does not seem to be an adequate option to assess the abductor musculature, since more than half of the world’s population is overweight and these strength values can be overestimated [56,57].

The determination of the force required by abductor muscles to body balance in a standing position depends on two variables: pelvic anatomy and body weight [59]. In the present study, since there was a pairing in relation to gender, age, and height, it is considered that there was a similarity in the pelvic anatomy between the pairs. Since the examination was performed by a single examiner, weight was the only relevant variable that could interfere with the sample strength.

When the statistical analysis of the factor loads was performed, it was possible to differentiate two distinct groups for all gluteus medius force variables, regardless of normalization with weight. This indicates that both the absolute strength values and those related to weight were different, constituting two distinct groups: the obese group and the normal weight group or control.

Obese individuals generally struggle to move their body mass. A lack of strength, observed specifically in sarcopenic obesity, culminates in functional adaptations and imbalance, predisposing to injuries [12,60]. The gluteal strength of obese individuals is a relevant factor since these two variables are independently associated with musculoskeletal system alterations [23-30,61]. According to new scientific evidence, muscle strength is inversely and independently associated with all-cause mortality [62].

The present study has some limitations. First, the sample size was small. Therefore, further studies are needed to generalize the results found. Second, the sample was predominantly composed of women (92%). Although it does not interfere in the conclusions, since they were paired samples, it can represent a bias because men have greater strength than women and may not present similar results. Further studies are needed to prove if there are morphological and functional changes in obese gluteal muscles that may justify gait imbalances and associations with musculoskeletal disorders.

Conclusions

The findings of the present study suggest that obese and eutrophic individuals have the same medius gluteus absolute strength. However, since this muscle is the main gait stabilizer and its strength is directly related to body weight, it was expected that obese individuals would have greater strength to move more mass, which did not happen. When data were normalized in relation to weight, there was a statistically significant difference between pairs, with obese individuals being weaker. In the PCA analysis, all strength variables, both absolute and normalized with weight, showed differences between groups. Since obesity is an epidemic in which the majority of the world's population is above ideal weight, it is recommended that the strength of gluteal muscles is always correlated with weight.

List Of Abbreviations

BMI - body mass index

cm – centimeters

ICC – intra-class correlation coefficient

kg - kilograms

LGM - left gluteus medius muscle

m - meters

N - Newtons

N/kg – Newtons per kilograms

PCA - principal component analysis

RGM - right gluteus medius muscle

UNIOESTE – Universidade Estadual do Oeste do Paraná

USA – United States of America

Declarations

Ethics approval and consent to participate

The UNIOESTE (Universidade Estadual do Oeste do Paraná) Human Research Ethics Committee approved the researche in July 2015 by the number 1.180.202.

Consent for publication

All individuals participating in this research signed an informed consent form prior to their inclusion in the study.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

There were no sources of funding for the reported research.

Authors' contributions

RRF – performed the examination of the individuals and was a major contributor in writing the manuscript.

ACFA – conducted the research and guided the data collection.

ATBG – analyzed and interpreted the individuals data.

All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

Authors' information

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Zaghloul A, Mohamed EM. Hip joint: embryology, anatomy and biomechanics. BJSTR. 2018; 12: 9304-18.
2. Correa TA, Crossley KM, Kim hJ, Pandy MG. Contributions of individual muscles to hip joint contact force in normal walking. J Biomech. 2010; 43: 1618-22.
3. Madeti BK, Rao CS, Rao BSKSS. Biomechanics of hip joint: a review. Int J Biomed Eng Technol. 2014; 15: 341.
4. Heller MO, Bergmann G, Kassi JP, Claes L, Hass NP, Duda GN. Determination of muscle loading at the hip joint for use in pre-clinical testing. J Biomech. 2005; 38: 1155-63.
5. John CT, Seth A, Schwartz MH, Delp SL. Contributions of muscles to mediolateral ground reaction force over a range of walking speeds. J Biomech. 2012; 45: 2438-43.
6. Frankel VH, Pugh JW. Biomechanics of the hip. In: Tronzo RG. Surgery of the hip joint. New York: Springer; 1984. p. 115-131.
7. Byrne DP, Mulhall KJ, Baker JF. Anatomy & biomechanics of the hip. Open Sports Med J. 2010; 4: 51-7.
8. Callanghan JJ, Rosenberg AG, Rubash HE. The adult hip. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 2007.
9. Harrasser N, Banke I, Gollwitzer H, Wilken F, Toepfer A, von Eisenhart-Rothe R, et al. Gluteale insuffizienz: pathogenese, diagnostik und therapie. Z Orthop Unfall. 2016; 154: 140-7.
10. Lai PP, Leung AK, Li AN, Zhang M. Three-dimensional gait analysis of obese adults. Clin Biomech. 2008; 23 Suppl 1: S2–6.
11. Silva-Hamu TC, Formiga CK, Gervásio FM, Ribeiro DM, Christofoletti G, de França Barros J. The impact of obesity in the kinematic parameters of gait in young women. Int J Gen Med. 2013; 6: 507-13.

12. Capodaglio P, Cimolin V, Tacchini E, Parisio C, Galli M. Balance control and balance recovery in obesity. Curr Obes Rep. 2012; 1: 166-73.
13. Lerner ZF, Board WJ, Browning RC. Effects of obesity on lower extremity muscle function during walking at two speeds. Gait Posture. 2014; 39: 978-84.
14. Rosso V, Agostini V, Takeda R, Tadano S, Gastaldi L. Influence of BMI on gait characteristics of young adults: 3D evaluation using inertial sensors. Sensors. 2019; 19: 4221.
15. Chi AS, Long SS, Zoga AC, Read PJ, Deely DM, Parker L, et al. Prevalence and pattern of gluteus medius and minimus tendon pathology and muscle atrophy in older individuals using MRI. Skeletal Radiol. 2015; 44: 1727-33.
16. Roubenoff R. Sarcopenic obesity: does muscle loss cause fat gain? Lessons from rheumatoid arthritis and osteoarthritis. Ann N Y Acad Sci. 2000; 904: 553-7.
17. Narici MV, Maffulli N. Sarcopenia: characteristics, mechanisms and functional significance. Br Med Bull. 2010; 95:139-59.
18. Schrager MA, Metter EJ, Simonsick E, Ble A, Bandinelli S, Laurentani F, et al. Sarcopenic obesity and inflammation in the InCHIANTI study. J Appl Physiol. 2007; 102: 919-25.
19. Erskine RM, Tomlinson DJ, Morse CI, Winwood K, Hampson P, Lord JM, et al. The individual and combined effects of obesity- and ageing-induced systemic inflammation on human skeletal muscle properties. Int J Obes. 2017; 41: 102-11.
20. Masgrau A, Mishellany-Dutour A, Murakami H, Beaufrère AM, Walrand S, Giraudet C, et al. Time-course changes of muscle protein synthesis associated with obesity-induced lipotoxicity. J Physiol. 2012; 590: 5199-210.
21. Kim TN, Park MS, Ryu JY, Choi HY, Hong HC, Yoo HJ, et al. Impact of visceral fat on skeletal muscle mass and vice versa in a prospective cohort study: the Korean Sarcopenic Obesity Study (KSOS). PLoS One. 2014; 9: e115407.
22. Shultz SP, Byrne NM, Hills AP. Musculoskeletal function and obesity: implications for physical activity. Curr Obes Rep. 2014; 3: 355-60.
23. Cooper NA, Scavo KM, Strickland KJ, Tipayamongkol N, Nicholson JD, Bewyer DC, et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. Eur Spine J. 2016; 25: 1258-65.
24. Bewyer KJ, Bewyer DC, Messenger D, Kennedy CM. Pilot data: association between gluteus medius weakness and low back pain during pregnancy. Iowa Orthop J. 2009; 29: 97-9.
25. Hinman RS, Hunt MA, Creacy MW, Wrigley TV, McManus FJ, Bennell KL. Hip muscle weakness in individuals with medial knee osteoarthritis. Arthritis Care and Res. 2010; 62: 1190-3.
26. Rowe J, Shafer L, Kelley K, West N, Dunning T, Smith R, et al. Hip strength and knee pain in females. N Am J Sports Phys Ther. 2007; 2: 164-9.
27. Bolgla LA, Malone TR, Umberger BR, Uhl TL. Comparison of hip and knee strength and neuromuscular activity in subjects with and without patellofemoral pain syndrome. Int J Sports Phys

Ther. 2011; 6: 285-96.

28. Sims KJ, Richardson CA, Brauer SG. Investigation of hip abductor activation in subjects with clinical unilateral hip osteoarthritis. Ann Rheum Dis. 2002; 61: 687-92.
29. Loureiro A, Mills PM, Barrett RS. Muscle weakness in hip osteoarthritis: a systematic review. Arthritis Care Res. 2013; 65: 340-52.
30. Grotle M, Hagen KB, Natvig B, Dahl FA, Kvien TK. Obesity and osteoarthritis in knee, hip and/or hand: an epidemiological study in the general population with 10 years follow-up. BMC Musculoskelet Disord. 2008; 9: 132.
31. Bohannon RW. Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. Arch Phys Med Rehabil. 1997; 78: 26-32.
32. Cuthbert SC, Goodheart GJ Jr. On the reliability and validity of manual muscle testing: a literature review. Chiropr Osteopat. 2007; 15:4.
33. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. PM&R. 2011; 3: 472-9.
34. Kolber MJ, Cleland JA. Strength testing using hand-held dynamometry. Phys Ther Rev. 2005; 10: 99-112.
35. Jackson SM, Cheng MS, Smith AR Jr, Kolber MJ. Intrarater reliability of hand held dynamometry in measuring lower extremity isometric strength using a portable stabilization device. Musculoskelet Sci Pract. 2017; 27: 137-41.
36. Martins J, da Silva JR, da Silva MRB, Bevilaqua-Grossi D. Reliability and validity of the belt-stabilized handheld dynamometer in hip- and knee-strength tests. J Athl Train. 2017; 52: 809-19.
37. Eknoyan G. Adolphe Quetelet (1796-1874) - The average man and indices of obesity. Nephrol Dial Transplant. 2008; 23: 47-51.
38. World Health Organization. Non communicable diseases country profiles 2014. Genève: WHO Press; 2014. p. 1-210.
39. Mior SA. Muscle testing, techniques of manual examination. J Can Chiropr Assoc. 1985; 29: 49.
40. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. J Orthop Sports Thys Ther. 2003; 33: 671-6.
41. Hislop HJ, Montgomery J. Daniels and Worthingham's muscle testing: techniques of manual examination. 8th ed. Philadelphia: Saunders; 2007.
42. Benfica PDA, Aguiar LT, Brito SAF, Bernardino LHN, Teixeira-Salmela LF, Faria CDCM. Reference values for muscle strength: a systematic review with a descriptive meta-analysis. Braz J Phys Ther. 2018; 22: 355-69.
43. Artaud F, Singh-Manoux A, Dugravot A, Tavernier B, Tzourio C, Elbaz A. Body mass index trajectories and functional decline in older adults: Three-City Dijon cohort study. Eur J Epidemiol. 2016; 31: 73-83.

44. Sugimoto D, Mattacola CG, Mullineaux DR, Palmer TG, Hewett TE. Comparison of isokinetic hip abduction and adduction peak torques and ratio between sexes. Clin J Sport Med. 2014; 24: 422-8.
45. Maffiuletti NA, Ratel S, Sartorio A, Martin V. The impact of obesity on in vivo human skeletal muscle function. Curr Obes Rep. 2013; 2: 251-60.
46. Tomlinson DJ, Erskine RM, Morse CI, Winwood MK, Onambélé-Pearson G. The impact of obesity on skeletal muscle strength and structure through adolescence to old age. Biogerontology. 2016; 17: 467-83.
47. Abdelmoula A, Martin V, Bouchant A, Walrand S, Lavet C, Taillardat M, et al. Knee extension strength in obese and nonobese male adolescents. Appl Physiol Nutr Metab. 2012; 37: 269-75.
48. Garcia-Vicencio S, Coudeyre E, Kluka V, Cardenoux C, Jegu AG, Fourot AV, et al. The bigger, the stronger? Insights from muscle architecture and nervous characteristics in obese adolescent girls. Int J Obes. 2015; 40: 245-51.
49. Bollinger LM. Potential contributions of skeletal muscle contractile dysfunction to altered biomechanics in obesity. Gait Posture. 2017; 56:100-7.
50. Amiri P, Hubley-Kozey CL, Landry SC, Stanish WD, Astephen Wilson JL. Obesity is associated with prolonged activity of the quadriceps and gastrocnemii during gait. J Electromyogr Kinesiol. 2015; 25: 951-8.
51. Tallis J, Hill C, James RS, Cox VM, Seebacher F. The effect of obesity on the contractile performance of isolated mouse soleus, EDL, and diaphragm muscles. J Appl Physiol. 2017; 122: 170-81.
52. Pacicco T, Ratner S, Xi Y, Yokoo T, Fetzer D, Oz OK, et al. Pelvic muscle size and myosteatosis: relationship with age, gender, and obesity. Indian J Radiol Imaging. 2019; 29: 155-62.
53. Duvigneaud N, Matton L, Wijndaele K, Deriemaeker P, Lefevre J, Philippaerts R, et al. Relationship of obesity with physical activity, aerobic fitness and muscle strength in Flemish adults. J Sports Med Phys Fitness. 2008; 48: 201-10.
54. Maffiuletti NA, Jubeau M, Agosti F, De Col A, Satorio A. Quadriceps muscle function characteristics in severely obese and nonobese adolescents. Eur J Appl Physiol. 2008; 103: 481-4.
55. Lafortuna CL, Maffiuletti NA, Agosti F, Sartorio A. Gender variations of body composition, muscle strength and power output in morbid obesity. Int J Obes. 2005; 29: 833-41.
56. OECD Obesity Update 2017. Organization for Economic Co-operation and Development, Paris. 2017. http://www.oecd.org/health/obesity-update.htm. Accessed 9 Feb 2020.
57. Kushner RF, Kahan S. Introduction: the state of obesity in 2017. Med Clin North Am. 2018; 102: 1-11.
58. Alvarenga G, Kiyomoto HD, Martinez EC, Polesello G, Alves VLDS. Normative isometric hip muscle force values assessed by a manual dynamometer. Acta Ortop Bras. 2019; 27: 124-8.
59. Daniel M, Hornová J, Doubrava K, Tomanová M. Biomechanical analysis of local and global strengthening of gluteus medius. Turk J Phys Med Rehabil. 2017; 63: 283-5.
60. Teasdale N, Simoneau M, Corbeil P, Handrigan G, Tremblay A, Hue O. Obesity alters balance and movement control. Curr Obes Rep. 2013; 2: 235-40.

61. Francisco V, Pérez T, Pino J, López V, Franco E, Alonso A, et al. Biomechanics, obesity, and osteoarthritis. The role of adipokines: when the levee breaks. J Orthop Res. 2018; 36: 594-604.
62. Volaklis KA, Halle M, Meisinger C. Muscular strength as a strong predictor of mortality: a narrative review. Eur J Intern. 2015; 26: 303-10.

Figures

A

B

Figure 1

a) Posterior and b) superior view of the position used to measure gluteus medius strength.

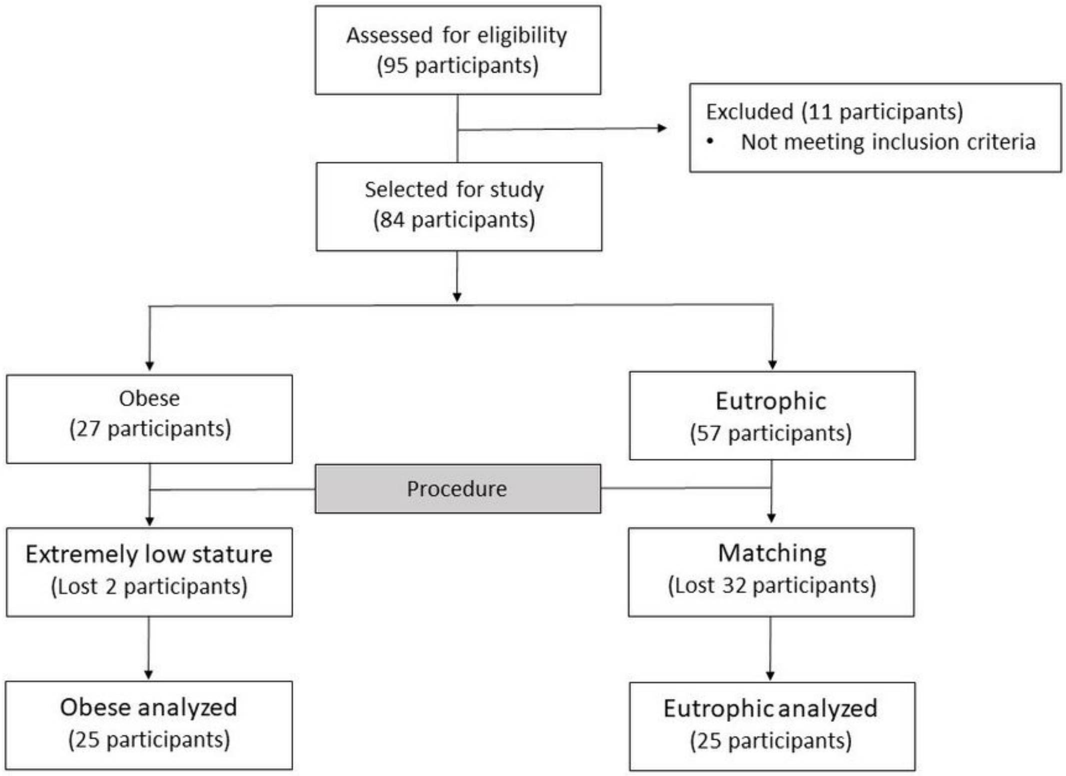

Figure 2

Diagram showing the flow of patient participants through the trial.

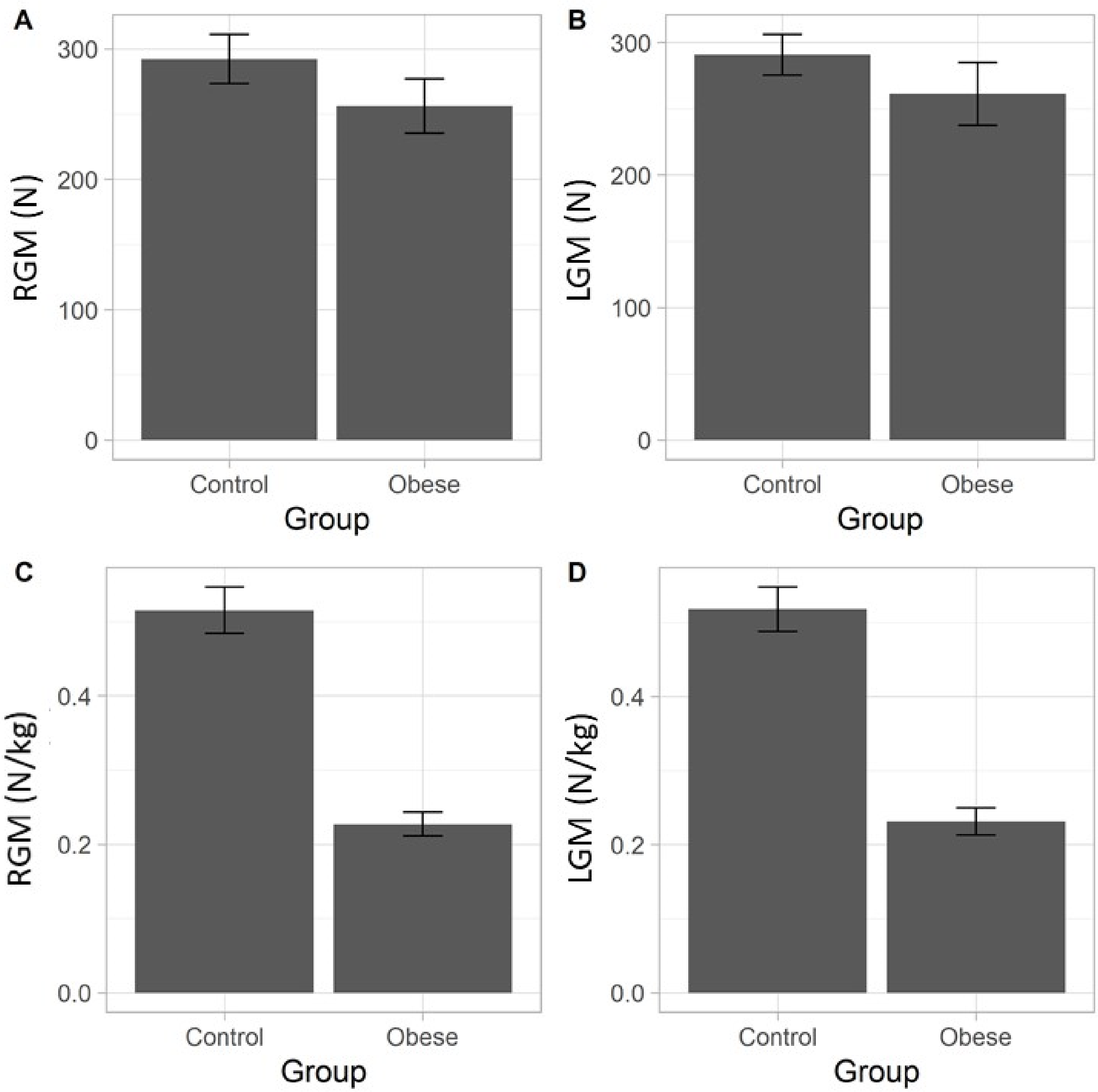

Figure 3

Comparative graphs showing the difference between RGM and LGM. Legends: a) RGM in N; b) LGM in N; c) RGM in N / Kg; d) LGM in N / Kg.

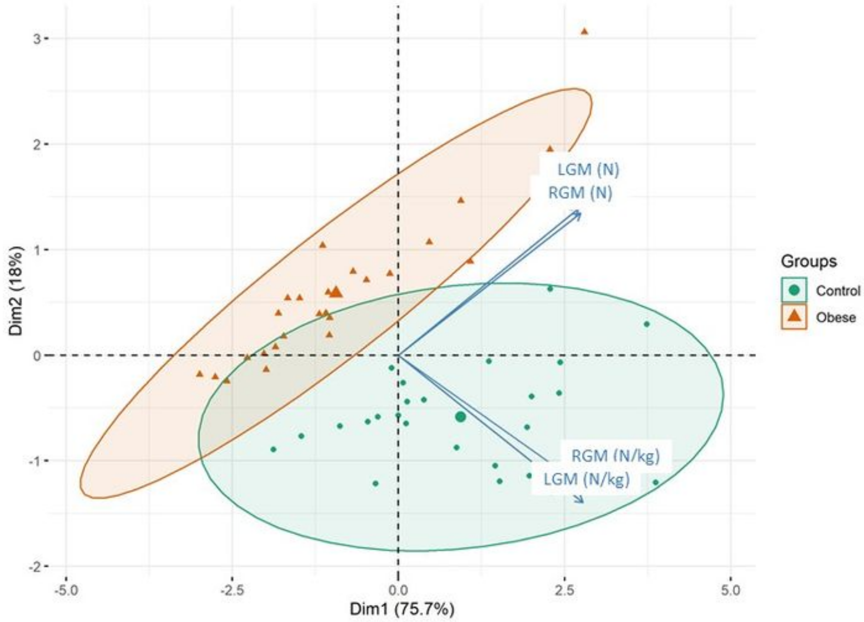

Figure 4

Diagram of the Main Component Analysis. Legends: RGM – right gluteus medius in N / kg; LGM – left gluteus medius in N / kg; RGM N – right gluteus medius in N; LGM N – left gluteus medius in N. Control (green ellipse) and obese (orange ellipse) groups.

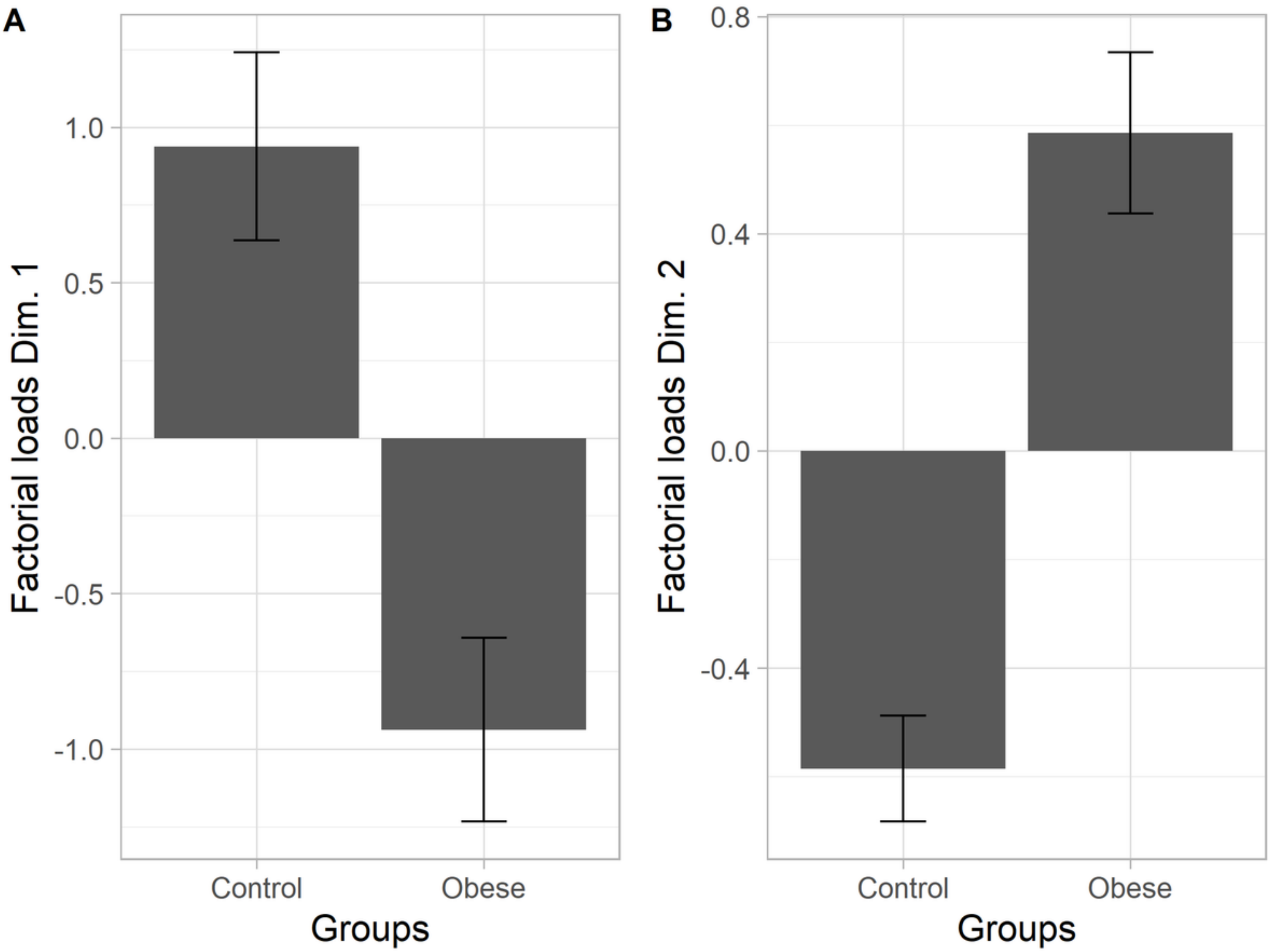

Figure 5

Means and standard errors of factor loads of main components for control and obese groups. Legends: a) First Main Component; b) Second Main Component.

Supplementary Files

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