Reduced exercise capacity for muscle mass in adolescents living with obesity

Larry Lands[1], Juliano Colapelle[2], Julie St-Pierre[1], and Julius Erdstein[1]

[1]McGill University Health Centre
[2]McGill University Faculty of Medicine and Health Sciences

September 19, 2023

Abstract

Background Adolescents living with obesity (AlwO) can have limited exercise capacity. Exercise capacity can be predicted by a 2-factor model comprising lung function and leg muscle function, but no study has looked at cycling leg muscle function and its contribution to cycling exercise capacity in AlwO. Methods 22 nonobese adolescents and 22 AlwO (BMI>95 percentile) were studied. Anthropometry, body composition (DEXA), spirometry, 30-sec isokinetic work capacity, and maximal exercise (cycle ergometry) were measured. Results AlwO had greater lean leg mass (LLM) (14.8±4.1 vs 21.0±4.3 kg, Con vs AlwO $p<0.001$). Lung function did not differ, although FEV_1 trended higher in AlwO (101.0±13.1 vs 107.9±12.7 percent predicted, $p=0.08$). Leg 30-second work output did not differ in absolute terms or per allometrically scaled LLM. Peak oxygen consumption did not differ between the groups in absolute terms or as percent predicted values (78.5±15.4 vs 82.1±16.5 percent predicted), but was lower in AlwO when expressed per scaled kg of LLM. Peak oxygen consumption related to both lung function and 30-second work capacity, with no observed group effect. 30-second leg work capacity related to the scaled muscle mass, with a small group effect. There was some correlation between leg work capacity and time spent in moderate to vigorous physical activity in AlwO ($r_s=0.39$, $p=0.07$). Conclusion AlwO have larger LLM and preserved exercise capacity, when expressed as percentage of predicted, but not per allometrically scaled LLM. Increasing time spent in moderate to vigorous activity may benefit AlwO.

Reduced exercise capacity for muscle mass in adolescents living with obesity

Juliano Colapelle[1], Julie St-Pierre[2], Julius Erdstein[3], Larry C. Lands[4]

[1]McGill University Experimental Medicine - Montréal (QC) (Canada)

[2]McGill University Health Centre, General Pediatrics, Maison de Santé Prévention Clinique 180 - Montréal (QC) (Canada)

[3]McGill University Health Centre Adolescent Medicine - Montréal (QC) (Canada)

[4]McGill University Health Centre Pediatric Respiratory Medicine - Montréal (QC) (Canada)

Corresponding author: Larry C. Lands, email: larry.lands@mcgill.ca

Abstract

Background

Adolescents living with obesity (AlwO) can have limited exercise capacity. Exercise capacity can be predicted by a 2-factor model comprising lung function and leg muscle function, but no study has looked at cycling leg muscle function and its contribution to cycling exercise capacity in AlwO.

Methods

22 nonobese adolescents and 22 AlwO (BMI>95 percentile) were studied. Anthropometry, body composition (DEXA), spirometry, 30-sec isokinetic work capacity, and maximal exercise (cycle ergometry) were measured.

Results

AlwO had greater lean leg mass (LLM) (14.8±4.1 vs 21.0±4.3 kg, Con vs AlwO $p<0.001$). Lung function did not differ, although FEV_1 trended higher in AlwO (101.0±13.1 vs 107.9±12.7 percent predicted, $p=0.08$). Leg 30-second work output did not differ in absolute terms or per allometrically scaled LLM.

Peak oxygen consumption did not differ between the groups in absolute terms or as percent predicted values (78.5±15.4 vs 82.1±16.5 percent predicted), but was lower in AlwO when expressed per scaled kg of LLM.

Peak oxygen consumption related to both lung function and 30-second work capacity, with no observed group effect. 30-second leg work capacity related to the scaled muscle mass, with a small group effect. There was some correlation between leg work capacity and time spent in moderate to vigorous physical activity in AlwO ($r_s=0.39$, $p=0.07$).

Conclusion

AlwO have larger LLM and preserved exercise capacity, when expressed as percentage of predicted, but not per allometrically scaled LLM. Increasing time spent in moderate to vigorous activity may benefit AlwO.

Shared abstract

Adolescents living with obesity have reduced exercise capacity when scaled per LLM. They may benefit from increased time spent in moderate to vigorous activity.

Adolescent obesity rates continue to rise worldwide (1, 2). Obesity negatively impacts physical fitness (3), a predictor of current and future health (4, 5). Further, physical fitness is best assessed using maximal effort tests such as progressive exercise testing by cycle ergometry with gas exchange to determine the peak oxygen consumption (6).

Maximal exercise ability can be determined by a combination of lung function and leg muscle function (7, 8). In turn, leg muscle function is dependent mostly upon lean leg mass (LLM), and to a lesser extent, the amount of time spent in moderate to vigorous activity (MVPA). Obesity can adversely affect lung function through expiratory flow limitation leading to dynamic hyperinflation, excessive ventilation, and dyspnea (9). While many adolescents living with obesity (AlwO) have increased LLM and force (10-14), they may also spend less time in MVPA or more time in sedentary activity. This may decrease the quality of the muscle, such as aerobic capacity.

The contribution of leg muscular function to exercise capacity has had little study in AlwO. Long jump distance correlated with maximal cycling exercise capacity (15). However, LLM was not assessed and this explosive power manoeuvre is quite different than the activity done during cycling. Isokinetic knee extensor strength was higher in obese male adolescents compared to nonobese adolescents (16). Knee extensor is only one muscle group that participates in the cycling motion. Further, knee extensor strength was less when expressed per kg of thigh muscle mass. Others (11) have found that force was maintained when expressed per kg of muscle mass. Many of the differences between studies are likely due to a scaling issue. Normalization should result in the normalized outcome being unrelated to the normalization factor. When combining groups with different anthropometry, normalization by total body mass or even total muscle mass typically does not result in normalization (17, 18). Additionally, whole body mass may not accurately reflect LLM (17).

Direct measurement of leg muscle function during a full cycling motion can better represent the contribution of leg muscle function to exercise capacity. This can be done using short term isokinetic cycling, where the cycling speed is fixed and work output directly measured. Total work achieved over a 30-second bout of isokinetic cycling directly relates to maximal cycle ergometry exercise capacity (7, 8). When 30-second isokinetic work output is combined with lung function (FEV_1), maximal oxygen consumption can be reasonably predicted.

The present study aimed to look at the factors contributing to exercise limitation in AlwO, including anthropometric measures, time spent in MVPA and sedentary activity, lung function, isokinetic leg muscle function, and maximal exercise capacity by cycle ergometry. We hypothesized that exercise capacity in the AlwO would be mildly reduced due to decreased time spent in MVPA and/or more time spent being sedentary.

Methods

Ethics statement: The study was approved by the Pediatric Research Ethics Committee of the MUHC (Study no. 2022-8098).

Participants: AlwO (males and females, 12-18 years of age) (BMI>95 percentile) (19) were recruited from the Montreal Children's Hospital-McGill University Health Centre (MUHC) Adolescent Obesity Clinic and La Maison de Santé Prévention Adolescent Obesity Clinic. Non-obese, otherwise healthy, adolescents were also recruited from both clinics, as well as by friends and family of the AlwO.

Procedures

In advance of the study visit, participants were asked to not eat or exercise two hours prior to the visit (20). Participants were also told to limit their consumption of alcohol and caffeine 12 hours prior to the visit to ensure a state of normal hydration. Moreover, it was ensured that participants did not consume calcium pills 24 hours prior to testing, nor did they have any nuclear or barium scans 7 days prior to testing.

Anthropometry and Body Composition: Weight was measured on an electronic balance, height by stadiometry, and Body Mass Index (BMI) was calculated. Waist and hip circumferences were measured according to the protocol provided by the World Health Organisation (WHO), using a body measuring tape (21). Sexual maturation was assessed by self-reported Tanner scores using pictograms (22). Body composition was then measured using a dual-energy X-ray absorptiometry (DEXA) scanner. DEXA scans were taken using the Lunar iDXA by GE Healthcare powered by enCORE^{TM} software (Version 15), while the participant was lying down within the confines of the scan. From the scan, total body mass, lean body mass, total fat mass, and LLM were extracted. As done by others (23), chest mass and fat mass, and abdominal mass and fat mass, were also derived.

Questionnaires: Habitual physical activity level was assessed using the IPAQ-A (International Physical Activity Questionnaire for Adolescents). The IPAQ-A measured overall total physical activity and was scored in MET-minutes (metabolic equivalent of task) per week, according to MET values provided by the IPAQ Research Committee (24). Sedentary time was assessed using the ASAQ (Adolescent Sedentary Activity Questionnaire) (25). Participants were asked to think about a normal week, during school term, and to report how long they usually spent engaged in several different sedentary behaviours before and after school on each day of the week, as well as on each day of the weekend. Time spent in each category of sedentary behaviour and total time being sedentary were calculated for weekdays, weekend days and all days.

Spirometry was performed as per ATS/ERS standards (26) using multi-ethnic Global Lung Initiative predictive values (27).

Isokinetic cycling: Participants underwent a 30-sec isokinetic cycle test (Excalibur Sport Ergometer PFM 06 Version 10.14.0, Lode). This test fixed the pedalling speed and calculated force, total 30-second work, and fatiguability (peak force-end force)/(peak force) expressed as a percentage. Initially subjects were tested at a pedalling speed of 60 RPM. For ease of cycling, most were tested at a 90 RPM. Peak force and fatiguability differ when tested at 60 and 90 RPM, but 30-second work does not differ (28), so for analysis, the 30-second work (watts) was used. No predicted values are available for the isokinetic cycle used.

Progressive exercise testing: Following a rest period after performing isokinetic cycling, progressive exercise testing was performed by cycle ergometry with gas exchange while wearing a facemask (Vyntus^{TM} CPX powered by SentrySuite^{TM} Software Solution (V2.19.96)). A standard modified Godfrey protocol (1-minute incremental protocol) progressive exercise test, with workload increments increasing by 10, 15 or 20 W/min was employed. According to the participant's predicted maximal exercise capacity (29), the workload was selected to have the test completed in 8 – 12 minutes. The test was stopped when the participant could no longer maintain the 60 RPM cycling cadence. Maximal workload (29) and peak oxygen consumption (30) were recorded.

Data Analysis: With the control group having a mean value for maximal exercise capacity of 100% predicted and a SD of 20, and the group of AlwO having a mean value of 80% predicted, 22 subjects in each group would enable detection of this difference with a power of 0.90. For purposes of exercise and muscle function, we expressed data (presented as mean ± SD for normally distributed variables, median ± interquartile range) in terms of absolute values, percent predicted values and allometrically scaled values. Normality was assessed by Shapiro-Wilk test, equality of variances was assessed by Levene's test, and effect size was assessed by Cohen's d, which allowed for parametric testing to be used. When normality was demonstrated, groups were compared using Student t-test, and modeling of exercise capacity was done using Pearson correlation and forward stepwise regression. Nonparametric relations were assessed by Spearman rank correlation. When variables were not normally distributed, groups were compared by Mann Whitney U test. A p-value <0.05 was considered as significant. Statistical analysis was performed using statistical software (JASP Version 0.17 Intel, University of Amsterdam, Netherlands).

Scaling: The relation between size and function is best assessed using allometric scaling (31). This uses a power function (eg, peak oxygen consumption$=aX^{b}\exp^{(c.group)}$, where a is the proportionality coefficient, X is the mass to be scaled to, and b is the allometric scaling factor). Typically maximal exercise capacity is compared between groups by expressing maximal exercise capacity as per kg of body mass (implying a scaling factor b=1). However, employment of a scaling factor of 1 leaves large residual effects, even when using LLM in the evaluation of cycling performance (17, 18, 32). In the current study, allometric scaling was conducted to derive a scaling factor such that work per kg of LLM to the power of b did not correlate with LLM to the power of b.

Results

23 nonobese adolescents and 24 AlwO were recruited. As not all tests were completed for each participant, results of the 22 participants in each group (9 male/13 female nonobese, 12 male/10 female AlwO) with complete data are reported.

Anthropometric and lung function results are reported in Table 1. The groups did not differ with respect to sex distribution, age, height or level of sexual maturation. As expected, the AlwO group weighed more, had a greater BMI, waist and hip circumferences, and waist-to-hip ratio. Correspondingly, DEXA scanning demonstrated that the AlwO group had greater body mass, lean and fat mass, percent body fat, LLM, chest mass and chest fat mass, and abdominal mass and abdominal fat mass (Table 2). The AlwO group was less physically activity (total activity and MVPA) but did not spend more time being sedentary (Table 3).

The AlwO group tended to have greater lung function for their height (Table 4).

An allometric scaling factor (0.85, 95% confidence interval: 0.622, 1.085) for LLM was derived according to the method of Batterham and colleagues (31) using regression analysis of Peak Oxygen Consumption to LLM for the combined groups. The validity of this factor was confirmed as there was no significant correlation between maximal exercise capacity (Wmax or VO_2 Peak/(kg LLM)$^{0.85}$) and the scaled LLM.

The groups did not differ in 30-second isokinetic work capacity in absolute terms (9.42 ± 4.252 w vs 11.46 ± 4.657 w, control vs AlwO) or per scaled LLM (0.93 ± 0.260 vs 0.85 ± 0.249 w/(LLM)$^{0.85}$, control vs AlwO).

Maximal exercise capacity and Peak Oxygen Consumption did not differ between the groups in absolute terms and when expressed as a percent of predicted. However, when expressed per scaled LLM, both maximal exercise capacity and Peak Oxygen Consumption were reduced in the AlwO group (Table 5). Peak oxygen pulse did not differ between the groups (11.23 ± 3.89 vs 12.52 ± 2.90 mL/beat, control vs AlwO)

Maximal exercise, whether in watts or peak ml of oxygen consumed (VO_2 peak) correlated with both FEV_1 and 30-sec isokinetic work capacity, alone (Figure 1a-d) and combined (Wmax r=0.87, $p<0.001$; VO_2 Peak:

r=0.85, p<0.001), with no group effect. 30-second leg work capacity correlated with scaled LLM, with a difference between the groups (Figure 2). There was some correlation between leg work capacity and time spent in MVPA (r_s=0.39, p=0.07) in AlwO, but not the control group. There was no significant correlation between exercise capacity (Wmax, VO_2 Peak, 30-sec isokinetic work capacity) and the amount of time spent in MVPA. Time spent in MVPA also did not contribute significantly to the correlation of maximal exercise capacity (Wmax, VO_2 Peak) when FEV_1 and 30-sec isokinetic work capacity were factored in.

Discussion

When scaled to the amount of LLM (the active mass during cycling exercise), AlwO had reduced exercise capacity. Isokinetic leg work capacity correlated with LLM, but there was a steeper relation in AlwO. AlwO also spent less time in MVPA, although not more time in sedentary activities.

Lung function tended to be greater in AlwO. In a younger cohort of children, obesity did not affect spirometric values (23). Of note, the current population had a lower BMI percentile compared to the study of younger children (mean 98.55 vs 122.6), but a non-significant greater z-score (mean 2.33 vs 2.18). In addition, the average chest mass and abdominal mass, as a % of total mass, was lower in the current population. It is possible that the greater BMI percentile and relative chest and abdominal masses in the younger group counterbalanced any potential increase respiratory muscle strength induced by the work of breathing against the additional mass.

The amount of habitual MVPA was lower in AlwO. The IPAQ scale correlates with movement activities as assessed by accelerometry, even in obese youth (33-35). Standard Metabolic Equivalent(s) of Task (METS) calculations do not account for the extra energy expenditure associated with movement of the larger mass in obesity. It has been suggested that this should be scaled to lean tissue mass (36). However, the AlwO group still had reduced MVPA even when scaling to LLM (Table 3). As reported in a systematic review, sedentary time was not increased in AlwO (37).

Maximal exercise capacity between the nonobese adolescents and AlwO differed when using allometric scaling using LLM, but not in absolute or as a percent predicted values. Scaling is meant to correct for body size and remove its influence (32). This is particularly important in children. Our scaling factor of 0.85 (95% confidence interval: 0.622, 1.085) is higher than that (0.51 males, 0.45 females, confidence intervals not reported) previously found in a study of adults aged 20-80 years using cycle ergometry (38). These authors found that VO_2 peak per scaled LLM negatively correlated with age. Others have found scaling factors of 0.55-0.64 in children but scaling was to treadmill oxygen consumption and not cycle ergometry (17, 39). Thus, our scaling factor is in the range of those found by others. In the future, with larger sample sizes, sex specific scaling factors should be determined.

It is unclear why scaled exercise capacity was reduced in AlwO. Exercise capacity correlated with lung function and leg muscle function individually and combined, with no group differences. There was a group difference for leg work capacity compared to LLM, whether in absolute or when scaled. This is largely due to a lower leg work capacity in AlwO with smaller LLM (Figure 1e). None of the AlwO met criteria for the Metabolic Syndrome. However, the AlwO were less physically active, and for the AlwO, but not for the nonobese group, there was some correlation between leg work capacity and time spent in MVPA (r=0.44, p<0.05, r_s=0.39, p=0.07). Thus, it is possible that the amount of time spent in MVPA impacted our results. A larger sample size and measures that accurately capture the energy expenditure of AlwO and LLM would help clarify this. However, this does suggest that AlwO would benefit from programs aimed at increasing the habitual time spent in MVPA (40).

In conclusion, AlwO have larger LLM and often preserved exercise capacity, when looked on as percentage of predicted. Leg muscle performance in AlwO appears influenced by the amount of time habitually spent in MVPA. Increasing time spent in MVPA may benefit AlwO.

1. Jebeile H, Kelly AS, O'Malley G, Baur LA. Obesity in children and adolescents: epidemiology, causes, assessment, and management. Lancet Diabetes Endocrinol. 2022;10(5):351-65.

2. Tyson N, Frank M. Childhood and adolescent obesity definitions as related to BMI, evaluation and management options. Best Pract Res Clin Obstet Gynaecol. 2018;48:158-64.

3. D'Agostino EM, Day SE, Konty KJ, Armstrong SC, Skinner AC, Neshteruk CD. Longitudinal Association between Weight Status, Aerobic Capacity, Muscular Strength, and Endurance among New York City Youth, 2010-2017. Child Obes. 2023;19(3):203-12.

4. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. International Journal of Obesity. 2008;32(1):1-11.

5. Lang JJ, Tomkinson GR, Janssen I, Ruiz JR, Ortega FB, Léger L, et al. Making a Case for Cardiorespiratory Fitness Surveillance Among Children and Youth. Exercise and Sport Sciences Reviews. 2018;46(2):66-75.

6. Raghuveer G, Hartz J, Lubans DR, Takken T, Wiltz JL, Mietus-Snyder M, et al. Cardiorespiratory Fitness in Youth: An Important Marker of Health: A Scientific Statement From the American Heart Association. Circulation. 2020;142(7).

7. Lands LC, Heigenhauser GJ, Jones NL. Analysis of factors limiting maximal exercise performance in cystic fibrosis. Clin Sci (Lond). 1992;83(4):391-7.

8. Haccoun C, Smountas AA, Gibbons WJ, Bourbeau J, Lands LC. Isokinetic muscle function in COPD. Chest. 2002;121(4):1079-84.

9. Grzyb A, Domagalska-Szopa M, Siwiec A, Kwiecień-Czerwieniec I, Szopa A. Cardiopulmonary Capacity in Overweight and Obese Children and Adolescents: A Cross-Sectional Study. Front Physiol. 2021;12:671827.

10. Thivel D, Ring-Dimitriou S, Weghuber D, Frelut ML, O'Malley G. Muscle Strength and Fitness in Pediatric Obesity: a Systematic Review from the European Childhood Obesity Group. Obes Facts. 2016;9(1):52-63.

11. Maffiuletti NA, Jubeau M, Agosti F, De Col A, Sartorio A. Quadriceps muscle function characteristics in severely obese and nonobese adolescents. Eur J Appl Physiol. 2008;103(4):481-4.

12. Maffiuletti NA, Ratel S, Sartorio A, Martin V. The Impact of Obesity on In Vivo Human Skeletal Muscle Function. Current Obesity Reports. 2013;2(3):251-60.

13. Tomlinson DJ, Erskine RM, Morse CI, Winwood K, Onambélé-Pearson G. The impact of obesity on skeletal muscle strength and structure through adolescence to old age. Biogerontology. 2016;17(3):467-83.

14. Tallis J, James RS, Seebacher F. The effects of obesity on skeletal muscle contractile function. Journal of Experimental Biology. 2018;221(13):jeb163840.

15. Reid RER, Fillon A, Thivel D, Henderson M, Barnett TA, Bigras JL, et al. Can anthropometry and physical fitness testing explain physical activity levels in children and adolescents with obesity? J Sci Med Sport. 2020;23(6):580-5.

16. 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(2):269-75.

17. Tolfrey K, Barker A, Thom JM, Morse CI, Narici MV, Batterham AM. Scaling of maximal oxygen uptake by lower leg muscle volume in boys and men. J Appl Physiol (1985). 2006;100(6):1851-6.

18. Lolli L, Batterham AM, Weston KL, Atkinson G. Size Exponents for Scaling Maximal Oxygen Uptake in Over 6500 Humans: A Systematic Review and Meta-Analysis. Sports Medicine. 2017;47(7):1405-19.

19. Lee EY, Yoon KH. Epidemic obesity in children and adolescents: risk factors and prevention. Front Med. 2018;12(6):658-66.

20. Akinkuotu AC, Hamilton JK, Birken C, Toulany A, Strom M, Noseworthy R, et al. Evolution and Outcomes of a Canadian Pediatric Bariatric Surgery Program. J Pediatr Surg. 2019;54(5):1049-53.

21. Patry-Parisien J, Shields M, Bryan S. Comparison of waist circumference using the World Health Organization and National Institutes of Health protocols. Health Rep. 2012;23(3):53-60.

22. Joensuu L, Kujala UM, Kankaanpää A, Syväoja HJ, Kulmala J, Hakonen H, et al. Physical fitness development in relation to changes in body composition and physical activity in adolescence. Scand J Med Sci Sports. 2021;31(2):456-64.

23. Wilhite DP, Bhammar DM, Martinez-Fernandez T, Babb TG. Mechanical effects of obesity on central and peripheral airway resistance in nonasthmatic early pubescent children. Pediatric Pulmonology. 2022;57(12):2937-45.

24. Ottevaere C, Huybrechts I, De Bourdeaudhuij I, Sjostrom M, Ruiz JR, Ortega FB, et al. Comparison of the IPAQ-A and actigraph in relation to VO2max among European adolescents: the HELENA study. J Sci Med Sport. 2011;14(4):317-24.

25. Hardy LL, Booth ML, Okely AD. The reliability of the Adolescent Sedentary Activity Questionnaire (ASAQ). Prev Med. 2007;45(1):71-4.

26. Graham BL, Steenbruggen I, Miller MR, Barjaktarevic IZ, Cooper BG, Hall GL, et al. Standardization of spirometry 2019 update. An official American thoracic society and European respiratory society technical statement. American journal of respiratory and critical care medicine. 2019;200(8):e70-e88.

27. Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, et al. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. 2012.

28. Jones NL, McCartney N, Graham T, Spriet LL, Kowalchuk JM, Heigenhauser GJ, et al. Muscle performance and metabolism in maximal isokinetic cycling at slow and fast speeds. J Appl Physiol (1985). 1985;59(1):132-6.

29. Godfrey S, Davies CT, Wozniak E, Barnes CA. Cardio-respiratory response to exercise in normal children. Clin Sci. 1971;40(5):419-31.

30. Orenstein DM. Assessment of exercise pulmonary function. In: Rowland TW, editor. Laboratory Exercise Testing Clinical Guidelines. Champaign: Human Kinetics; 1993. p. 141-63.

31. Batterham AM, Vanderburgh PM, Mahar MT, Jackson AS. Modeling the influence of body size onV.<scp>o</scp>_{2 peak}: effects of model choice and body composition. Journal of Applied Physiology. 1999;87(4):1317-25.

32. Tomlinson OW, Barker AR, Oades PJ, Williams CA. Scaling the Oxygen Uptake Efficiency Slope for Body Size in Cystic Fibrosis. Medicine & Science in Sports & Exercise. 2017;49(10):1980-6.

33. Hagströmer M, Bergman P, De Bourdeaudhuij I, Ortega FB, Ruiz JR, Manios Y, et al. Concurrent validity of a modified version of the International Physical Activity Questionnaire (IPAQ-A) in European adolescents: The HELENA Study. International Journal of Obesity. 2008;32(S5):S42-S8.

34. Vanhelst J, Mikulovic J, Fardy PS, Bui-Xuan G, Béghin L. Concurrent validity of the modified International Physical Activity Questionnaire for French obese adolescents. Percept Mot Skills. 2013;116(1):123-31.

35. Regaieg S, Charfi N, Yaich S, Damak J, Abid M. The Reliability and Concurrent Validity of a Modified Version of the International Physical Activity Questionnaire for Adolescents (IPAQ-A) in Tunisian Overweight and Obese Youths. Med Princ Pract. 2016;25(3):227-32.

36. Tompuri TT. Metabolic equivalents of task are confounded by adiposity, which disturbs objective measurement of physical activity. Front Physiol. 2015;6:226.

37. Elmesmari R, Martin A, Reilly JJ, Paton JY. Comparison of accelerometer measured levels of physical activity and sedentary time between obese and non-obese children and adolescents: a systematic review. BMC Pediatrics. 2018;18(1).

38. Neder JA, Nery LE, Silva AC, Andreoni S, Whipp BJ. Maximal aerobic power and leg muscle mass and strength related to age in non-athlethic males and females. Eur J Appl Physiol Occup Physiol. 1999;79(6):522-30.

39. GRAVES LEF, BATTERHAM AM, FOWEATHER L, MCWHANNELL N, HOPKINS ND, BODDY LM, et al. Scaling of Peak Oxygen Uptake in Children: A Comparison of Three Body Size Index Models. Medicine & Science in Sports & Exercise. 2013;45(12):2341-5.

40. Jayasinghe S, Hills AP. Strategies to Improve Physical Activity and Nutrition Behaviours in Children and Adolescents: A Review. Nutrients. 2023;15(15):3370.

Figure 1: Maximal Exercise Capacity vs FEV_1 and 30-sec Leg Work Capacity in AlwO and Controls

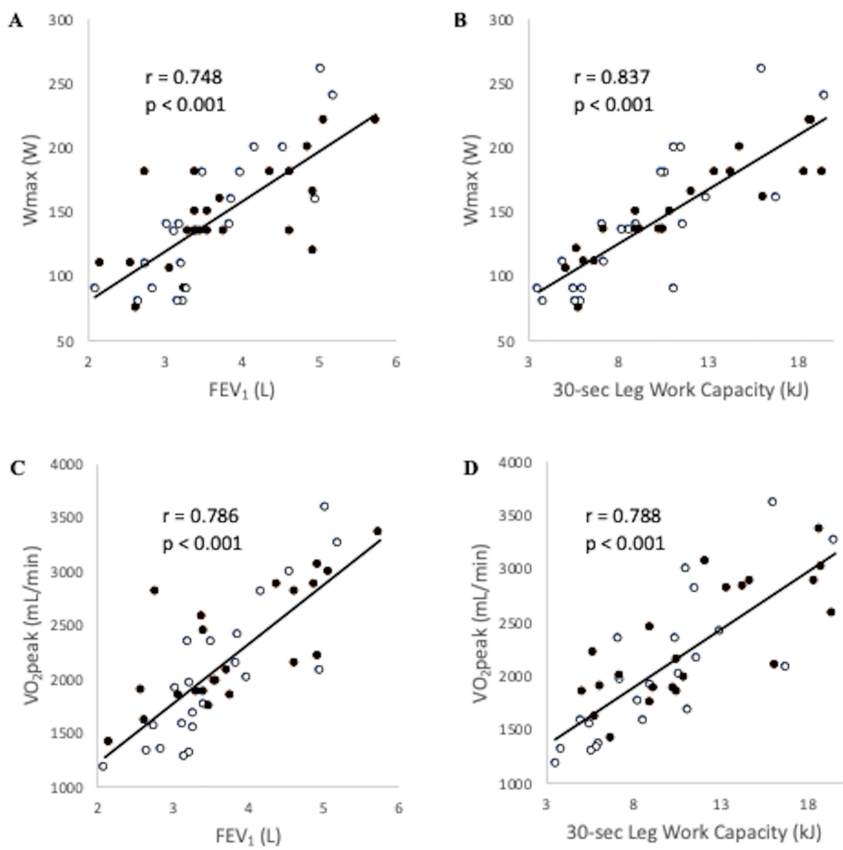
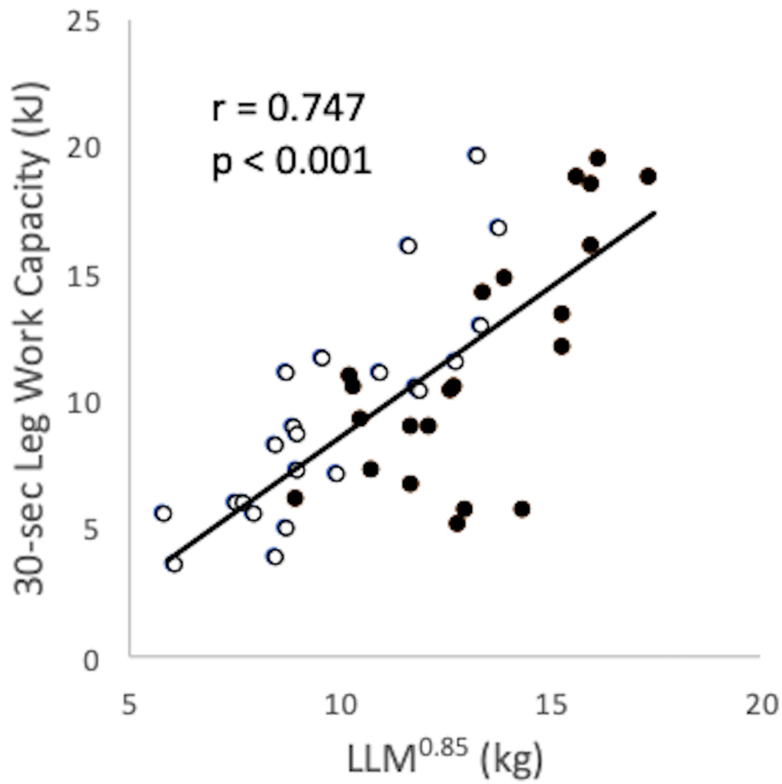


Figure 2: 30-sec Leg Work Capacity vs Scaled LLM in AlwO and Controls



Hosted file

`Lands Tables exercise limitation in adolescent obesity for submission.docx` available at https://authorea.com/users/451388/articles/667167-reduced-exercise-capacity-for-muscle-mass-in-adolescents-living-with-obesity