



# Adipose-to-muscle area ratio at the knee is superior to BMI in predicting post-operative outcome following arthroscopic meniscectomy

Amos Z. Dai<sup>1,3</sup> · Joshua Breite<sup>2</sup> · Hien Pham<sup>2</sup> · Michael Pickell<sup>2</sup> · Mark Kramarchuk<sup>2</sup> · Eduardo Vaca<sup>2</sup> · Eric J. Strauss<sup>2</sup>

Received: 25 January 2018 / Published online: 24 August 2018  
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

## Abstract

**Purpose** To determine if measurement of leg adipose tissue area by MRI is a better predictor of post-operative clinical outcome compared to body mass index (BMI) following arthroscopic meniscectomy.

**Methods** Patients that underwent an arthroscopic partial meniscectomy between 2011 and 2016 were identified and a retrospective chart review was performed. Patients with additional knee pathology other than a meniscal tear with or without associated articular cartilage injury were excluded. Leg adipose tissue and muscle area measurements at the level of the knee joint were performed for patients on their preoperative axial magnetic resonance imaging (MRI) study and adipose-to-muscle area ratio (AMR) was calculated. Correlations among AMR, BMI, and post-operative clinical outcomes were compared.

**Results** A total of 74 patients (32 females and 42 males) were included (mean age 50.0 years, std. dev. 12.3 years). 35 patients underwent a partial medial meniscectomy, 15 underwent a partial lateral meniscectomy, and 24 underwent both. Linear regression analysis showed that the AMR, compared to BMI, had a significantly stronger correlation to both mean post-operative Knee Injury and Osteoarthritis Outcome Score (KOOS) across all 5 subscales (KOOS<sub>5</sub>) and Tegner Current score. Patients that had cartilage damage and concurrent chondroplasty tended to be older and have lower post-operative KOOS<sub>5</sub> compared to those with no cartilage damage. AMR was also significantly correlated to age and BMI.

**Conclusions** The current study demonstrates that compared to BMI, leg adiposity as determined by the ratio of adipose tissue to muscle area on axial MRI (AMR), is a stronger predictor of functional outcome following meniscectomy. This suggests a role of obesity in the progression of OA beyond the increased joint forces associated with increased BMI.

**Level of evidence** IV, retrospective case series.

**Keywords** Meniscectomy · Body mass index · Arthroscopy · Leg adipose tissue · Obesity

## Introduction

Obesity is currently considered an epidemic and is associated with numerous general medical comorbidities including osteoarthritis (OA) [1]. According to the 2011–2014

National Health and Nutrition Examination Survey (NHANES), 36.5% of adults in the United States were obese [2], which is defined as body mass index (BMI)  $\geq 30$  kg/m<sup>2</sup>. BMI is used to define obesity because it is convenient,

✉ Amos Z. Dai  
amos.z.dai@gmail.com

Joshua Breite  
18jzbreite@ecfs.org

Hien Pham  
hien.pham@nyumc.org

Michael Pickell  
mpickell@qmed.ca

Mark Kramarchuk  
mnk003@bucknell.edu

Eduardo Vaca  
Eduardo\_vaca@rush.edu

Eric J. Strauss  
eric.strauss@nyumc.org

<sup>1</sup> Stony Brook University Hospital, 101 Nicolls Rd, Stony Brook, NY 11794, USA

<sup>2</sup> NYU Langone Orthopedic Hospital, 301 E 17th St, New York, NY 10003, USA

<sup>3</sup> Staten Island, USA

safe, inexpensive, and usually correlates with the amount of body fat present [3].

Several studies have demonstrated a link between patient BMI and functional outcome following meniscectomy surgery [4–8]. In a recent systematic review, Kluczynski et al. concluded that increased BMI was associated with worse clinical outcome scores and less patient satisfaction after arthroscopic meniscectomy or debridement. Further, Thijsen et al. proposed that the link between obesity and OA may transcend excessive loading, with dyslipidemia and pro-inflammatory cytokines and adipokines potentially playing pivotal roles [9].

Although BMI is the most commonly used method to assess obesity, this method has been criticized because BMI is an indirect surrogate measurement [3] that does not always reflect true body composition, or adiposity [10]. It often misclassifies persons with increased body fat and normal BMI, as well as persons with increased muscle mass and increased BMI. Several indices have been proposed to address the shortcomings of using BMI to assess obesity and adiposity, including fat mass index, body fat percentage, body adiposity, a body shape and body roundness indices [10, 11].

The purpose of the current study was to determine if the ratio of adipose tissue area to muscle area by MRI at the level of the knee joint is a better predictor of postoperative clinical outcome compared to BMI after arthroscopic meniscectomy. It is hypothesized that this ratio would be more strongly correlated with both mean postoperative Knee Injury and Osteoarthritis Outcome Score (KOOS) across all five subscales (KOOS<sub>5</sub>) [Hypothesis 1] and Tegner Activity Level Scale [Hypothesis 2], compared to standard BMI calculation.

## Methods

### Study design

This was a single-center, retrospective case series study. Following approval from the institutional review board, 460 patients who had undergone arthroscopic partial meniscectomy by an academic hospital-based orthopaedic sports medicine surgeon between April 2011 and April 2016 were identified. Electronic medical records and charts were reviewed for inclusion and exclusion criteria. BMI values were calculated from patients' height and weight, measured at the patient's preoperative office visit by licensed medical assistants. Sociodemographic variables included age and sex.

Of the 460 patients, 34 were excluded because they had additional procedures performed other than a chondroplasty, 186 did not have a pre-operative magnetic resonance imaging (MRI) study available electronically, and 166 did not

complete the outcome score questionnaires (KOOS and Tegner Activity Level Scale) at 6-months or more after surgery. A flowchart summarizing the inclusion/exclusion process and examples of excluded procedures is presented in Fig. 1.

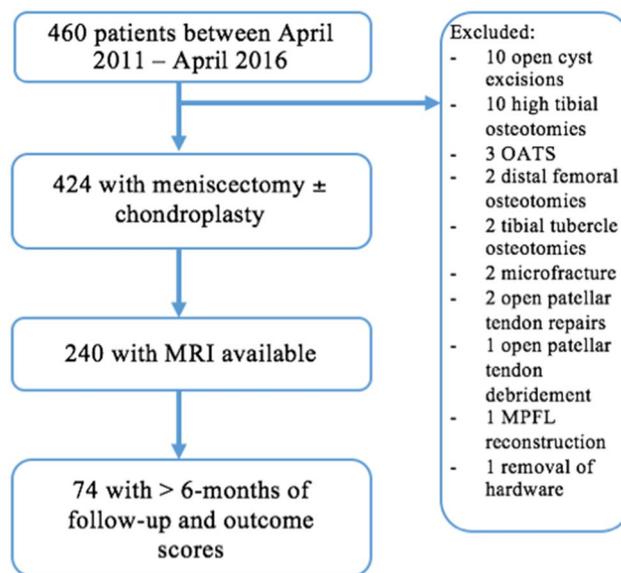
### Outcome parameters

Post-operative clinical outcome was assessed using KOOS [12] and Tegner Activity Level Scale [13] questionnaires. KOOS questionnaire responses were reported as KOOS<sub>5</sub>, the mean of the five individual subscale scores (symptoms, pain, activities of daily living, sports and recreation function, and quality of life).

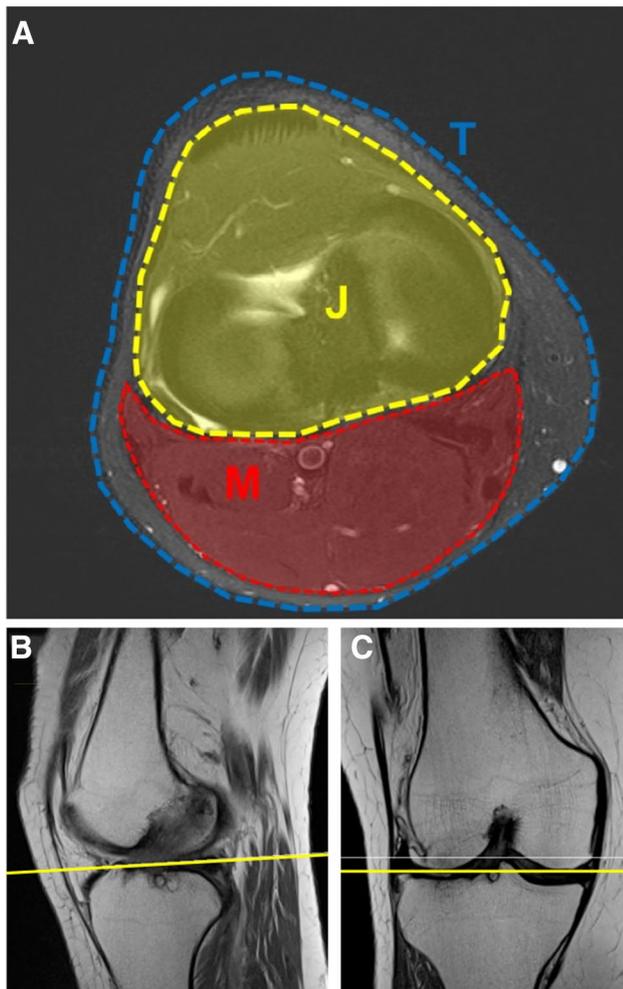
### Adipose-to-muscle area ratio (AMR) calculation

Adipose tissue area for each subject was measured on a single MRI axial plane image at the level of the knee joint. Sagittal and coronal MRI views were used to select the axial image that is most equidistant from the proximal tibia and distal femur. The area of the entire leg, area of the joint space, and area of the muscle space were traced and calculated using the authors' institution's medical imaging technology program (Phillips IntelliSpace PACS Enterprise) (Fig. 2). The adipose tissue area was then calculated by subtracting the joint space and muscle areas from the total area of the leg. AMR was calculated by dividing adipose tissue area by the muscle space area.

This method of estimating adiposity in the leg has not been previously described. Therefore, inter- and



**Fig. 1** Study inclusion process. *MRI* magnetic resonance imaging. *OATS* osteochondral autograft transfer system. *MPFL* medial patellofemoral ligament



**Fig. 2** a Axial MRI showing measurement of total leg area (*T*), joint space area (*J*), and muscle area (*M*). Leg adipose area (*A*) =  $T - (J + M)$ . Adipose-to-Muscle Ratio (AMR) =  $A/M$ . b Sagittal and c coronal MRI with yellow line depicting level of axial slice

intra-observer reliability has not yet been established. Although the validity of utilizing the AMR measurement (based on area) as a surrogate for total leg adiposity (based on volume) is yet to be determined, the authors believe it to be more valid than the traditional BMI calculation.

### Statistical analysis

Continuous variables are presented in terms of the mean, standard deviation, and range, while categorical variables are presented in terms of frequencies and percentages. One-way ANOVA and pairwise *t* tests were performed to determine if differences existed among cohorts based on nominal variables (male vs female, medial vs lateral vs combined meniscectomy, concurrent chondroplasty vs no concurrent chondroplasty), and if those differences were statistically significant. Univariate and multivariate linear regression

**Table 1** Patient characteristics

Age <sup>a</sup>	49.97 ± 12.29 (20.18–69.92)
BMI <sup>a</sup>	28.74 ± 5.59 (18.6–50.0)
Fat to muscle ratio <sup>a</sup>	2.35 ± 1.07 (0.90–5.59)
Sex <sup>b</sup>	
Male	32 (43.2%)
Female	42 (56.8%)
Meniscectomy <sup>b</sup>	
Medial only	35 (47.3%)
Lateral only	15 (20.3%)
Medial and lateral	24 (32.4%)
Chondroplasty <sup>b</sup>	
Yes	45 (60.8%)
No	29 (39.2%)

BMI body mass index ( $\text{kg}/\text{m}^2$ )

<sup>a</sup>Values given as mean ± standard deviation and range in parentheses

<sup>b</sup>Values given as number of patients and percentage in parentheses

analyses were performed to determine any correlations between continuous variables (age, BMI, AMR, KOOS<sub>5</sub>, and Tegner Activity Level scores). All data aggregation and statistical analysis was performed with SPSS 24 (IBM, Armonk NY).

### Results

Of 240 eligible patients with MRI available for analysis, 74 patients (mean age [and standard deviation] was 49.97 ± 12.3 years, range 20.18–69.92 years) completed minimum 6-month outcome questionnaires and were included in the final analysis (31% response rate). The mean time from surgery to follow-up and questionnaire completion was 23.2 ± 14.2 months (range 6–60.5 months). Table 1 summarizes the baseline characteristics of this patient population, which consisted of 32 females (43.2%) and 42 males (56.8%). Arthroscopic partial medial meniscectomy was performed in 35 patients (47.3%), partial lateral meniscectomy in 15 patients (20.3%), and both medial and lateral partial meniscectomy in 24 patients (32.4%). Intra-operatively, 45 patients (60.8%) were noted to have cartilage damage and shaving chondroplasty performed.

Postoperative KOOS<sub>5</sub> was scored on a scale of 0–100, with a mean score of 80.2 ± 17.2 (range 31.5–100.0) at mean 23.2 months. Tegner activity level consists of two scores (before injury and current), both rated on a scale from 0 to 10; the mean Tegner before score was 5.55 ± 2.58 (range 0–10.0) and mean current Tegner score at mean 23.2 months was 4.32 ± 2.22 (range 0–10.0). Linear regression showed that while both AMR and BMI were significant predictors of post-operative KOOS<sub>5</sub>, AMR was a stronger predictor (*r*

= -0.305,  $p=0.008$  vs.  $r = -0.237$ ,  $p=0.042$ ) [Hypothesis 1]. AMR also showed a significant correlation with the Tegner before score ( $r = -0.325$ ,  $p=0.005$ ) and current Tegner score ( $r = -0.378$ ,  $p=0.001$ ), while BMI was not significantly correlated to either ( $p=0.243$  and  $p=0.167$ , respectively) [Hypothesis 2].

AMR was also significantly correlated with age ( $r=0.329$ ,  $p=0.004$ ) and BMI ( $r=0.328$ ,  $p=0.004$ ). AMR tended to be higher in females (3.21 vs. [males] 1.70,  $p<0.001$ ) and in patients with both medial and lateral meniscus injury (2.86 vs. [lateral only] 2.28 vs. [medial only] 2.05,  $p=0.014$ ). Patients that had cartilage damage and concurrent chondroplasty tended to be older ( $54.97 \pm 9.37$  vs.  $42.22 \pm 12.39$  years,  $p<0.001$ ) and have lower post-operative KOOS<sub>5</sub> scores ( $76.97 \pm 17.2$ ,  $p=0.044$ ) compared to patients that did not have cartilage damage ( $85.2 \pm 16.32$ ,  $p=0.044$ ). There were no significant differences in outcome scores between patients with medial only, lateral only, or combined medial and lateral meniscectomies.

## Discussion

The current study found that leg adiposity (as measured by AMR) and BMI were significantly correlated to each other as well as to post-meniscectomy KOOS<sub>5</sub> and Tegner scores, suggesting that AMR and BMI share similar mechanisms in predicting poor clinical outcome following surgery. These include increased joint loading [14], decreased muscle strength and power [15], increased risk of falling [16] and increased surgical difficulty [4, 7]. More importantly, however, we found that when compared to BMI, AMR was more highly correlated with both postoperative KOOS<sub>5</sub> and Tegner Current scores.

Currently, BMI is used to define obesity because it is convenient, safe, inexpensive, and for most people, correlates with their amount of body fat [3]. Several studies have found associations between BMI and functional outcomes following meniscectomy surgery. For example, in a prospective nationwide study of 270 patients in Scotland, Bailey et al. [8] found that patients with BMI > 35 kg/m<sup>2</sup> had significantly lower post-operative EuroQol 5Q5D5L and KOOS<sub>5</sub> scores than patients with BMI < 30 kg/m<sup>2</sup>. Several studies have also demonstrated that increased BMI is a risk factor for the development of OA in post-meniscectomized knees [17]. However, the link between BMI and meniscectomy outcomes has not been upheld across all studies. In a recent systematic review, Kluczynski et al. [4] reported just three [5, 18, 19] of six [20–22] included studies found significant associations between BMI and outcomes after arthroscopic meniscectomy or debridement. The lack of consensus among studies regarding the association between BMI and meniscectomy outcomes may be due, in part, to the shortcomings

of using BMI as an indicator of body fatness or adiposity [10].

There are several potential explanations for the inconsistent link between BMI and clinical outcome scores. Obesity-related dyslipidemia, characterized by high plasma levels of triglycerides (TG), low density lipoprotein (LDL) cholesterol, free fatty acids (FFA), and low high density lipoprotein (HDL) cholesterol, has also been linked to the progression of OA through various inflammatory mechanisms [9]. Pro-inflammatory cytokines such as TNF- $\alpha$  and IL-6 are released by adipose tissue and the infrapatellar fat pad (IFPF) and have been shown to be elevated in the synovial fluid of OA patients [9, 23]. It has also been theorized that IL-6 can directly cause pain via sensitization of C fibers in the knee joint [24]. The inflammatory environment within the joint mediated by these cytokines can be damaging to articular and meniscal cartilage. Since BMI does not distinguish between adipose and muscle mass, AMR may be more directly associated with dyslipidemia and systemic inflammation. Although BMI may be a more direct measure of joint forces than AMR, our findings are consistent with these more recent theories linking adipose tissue and joint disease. In a recent study, Ateschrang et al. showed that obesity (BMI > 30) causes less favorable results in Constant and DASH scores and higher re-tear rates in individuals who underwent rotator cuff repair [25]. Although a possible explanation is that increased arm weight in obese individuals places higher mechanical stress on the shoulder and rotator cuff, dyslipidemia may have a larger effect on healing in this non weight-bearing joint.

Two related entities that may also contribute to the stronger correlation between AMR and post-meniscectomy outcomes are quadriceps muscle strength and activity level. Maffioletti et al. [15] found that relative quadriceps muscle torque and power were reduced in obese subjects. Again, due to the fact that BMI does not take into account the composition of mass (adipose tissue vs muscle), AMR may be a better marker of quadriceps weakness. Obese patients are also believed to have a more sedentary lifestyle, which should directly affect KOOS<sub>5</sub> scores, by nature of the survey questions. Compared to BMI, AMR may be a better indicator of patients' general activity level per our results: Tegner activity score before injury was found to be significantly correlated with AMR, but not with BMI.

Another drawback of using BMI to predict post-operative outcomes is its inability to indicate the distribution of mass in a patient's body. It has been postulated that increased BMI makes surgery more challenging and, therefore, should negatively affect outcomes [7]. When performing arthroscopic meniscectomy on an obese individual, manipulation of the leg and arthroscopic instruments becomes more difficult, since the leg is likely heavier and there is more adipose tissue to traverse. Compared to BMI, AMR is a measurement

more localized to the surgical area, which may contribute to its stronger correlation with functional outcomes post-meniscectomy.

Finally, extremes of BMI may be better predictors of clinical outcome than current BMI. In a case-control study of patients over the age of 50, Singer et al. found both lifetime maximum and minimum (over the age of 18 years) to be more highly predictive of knee OA [26]. Interestingly, the study also found that both weight distribution indicators (waist-circumference and waist-to-height-ratio) were more predictive of knee OA than of hip OA. This suggests that the knee, as compared to the hip, is more susceptible to metabolic damage associated with higher intra-abdominal fat mass.

The present study has several limitations. First, heterogeneity in this study exists, both with respect to patient population (meniscectomy alone vs concomitant chondroplasty) and with respect to questionnaire follow-up time. Due to the retrospective nature of the study, pre-operative KOOS<sub>5</sub> scores were not obtained. Therefore, the rate of improvement and its association with BMI or AMR could not be assessed. The correlations observed between post-meniscectomy outcomes and AMR or BMI may be largely due to patient's pre-operative condition, since patients with pre-operative articular cartilage damage (as determined intraoperatively) had significantly lower post-operative KOOS<sub>5</sub> scores than those who did not. Finally, this method of estimating adiposity in the leg has not yet been proven. Furthermore, its inter- and intra-observer reliability has not yet been established and should be a focus of future work.

Future studies should aim to investigate the effects of central versus leg adiposity on outcome following meniscectomy. Results showing AMR to be a stronger predictor may further reinforce the theory that poor outcome and articular disease are influenced by more than just increased mechanical forces. Although more time intensive than BMI calculation, the AMR calculation would allow surgeons to better assess risk for poor clinical outcome and need for additional modifications in preoperative diet and fitness regimens for patients undergoing arthroscopic meniscectomy.

## Conclusions

The current study demonstrates that compared to BMI, leg adiposity as determined by the ratio of adipose tissue to muscle area on axial MRI (AMR), is a stronger predictor of functional outcome following meniscectomy. This suggests a role of obesity in the progression of OA beyond the increased joint forces associated with increased BMI.

**Funding** There is no funding source.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** Ethical approval was obtained from the authors' Institutional Review Board (s-17-01185).

**Informed consent** Waiver of authorization and consent was approved by the authors' Institutional Review Board due to the retrospective nature of the study.

## References

1. Haviv B, Bronak S, Thein R (2015) Correlation between body mass index and chondral lesions in isolated medial meniscus tears. *Indian J Orthop* 49(2):176–180. <https://doi.org/10.4103/0019-5413.152456>
2. Ogden CL, Carroll MD, Fryar CD, Flegal KM (2015) Prevalence of obesity among adults and youth: United States, 2011–2014. *NCHS Data Brief* 219:1–8
3. Shah NR, Braverman ER (2012) Measuring adiposity in patients: the utility of body mass index (BMI), percent body fat, and leptin. *PLoS One* 7(4):e33308. <https://doi.org/10.1371/journal.pone.0033308>
4. Kluczynski MA, Bisson LJ, Marzo JM (2014) Does body mass index affect outcomes of ambulatory knee and shoulder surgery? *Arthroscopy* 30(7):856–865. <https://doi.org/10.1016/j.arthro.2014.02.031>
5. Erdil M, Bilsel K, Sungur M, Dikmen G, Tuncer N, Polat G, Elmadag NM, Tuncay I, Asik M (2013) Does obesity negatively affect the functional results of arthroscopic partial meniscectomy? A retrospective cohort study. *Arthroscopy* 29(2):232–237. <https://doi.org/10.1016/j.arthro.2012.08.017>
6. Sofu H, Oner A, Camurcu Y, Gursu S, Ucpunar H, Sahin V (2016) Predictors of the clinical outcome after arthroscopic partial meniscectomy for acute trauma-related symptomatic medial meniscal tear in patients more than 60 years of age. *Arthroscopy* 32(6):1125–1132. <https://doi.org/10.1016/j.arthro.2015.11.040>
7. Salata MJ, Gibbs AE, Sekiya JK (2010) A systematic review of clinical outcomes in patients undergoing meniscectomy. *Am J Sports Med* 38(9):1907–1916. <https://doi.org/10.1177/0363546510370196>
8. Bailey O, Gronkowski K, Leach WJ (2015) Effect of body mass index and osteoarthritis on outcomes following arthroscopic meniscectomy: a prospective nationwide study. *Knee* 22(2):95–99. <https://doi.org/10.1016/j.knee.2014.12.008>
9. Thijssen E, van Caam A, van der Kraan PM (2015) Obesity and osteoarthritis, more than just wear and tear: pivotal roles for inflamed adipose tissue and dyslipidaemia in obesity-induced osteoarthritis. *Rheumatology* 54(4):588–600. <https://doi.org/10.1093/rheumatology/keu464>
10. Liu P, Ma F, Lou H, Liu Y (2013) The utility of fat mass index vs. body mass index and percentage of body fat in the screening of metabolic syndrome. *BMC Public Health* 13:629. <https://doi.org/10.1186/1471-2458-13-629>
11. Santos DA, Silva AM, Matias CN, Magalhaes JP, Minderico CS, Thomas DM, Sardinha LB (2015) Utility of novel body indices in predicting fat mass in elite athletes. *Nutrition* 31(7–8):948–954. <https://doi.org/10.1016/j.nut.2015.02.003>
12. Collins NJ, Prinsen CA, Christensen R, Bartels EM, Terwee CB, Roos EM (2016) Knee Injury and Osteoarthritis Outcome Score (KOOS): systematic review and meta-analysis of measurement

- properties. *Osteoarthr Cartil* 24(8):1317–1329. <https://doi.org/10.1016/j.joca.2016.03.010>
13. Briggs KK, Kocher MS, Rodkey WG, Steadman JR (2006) Reliability, validity, and responsiveness of the Lysholm knee score and Tegner activity scale for patients with meniscal injury of the knee. *J Bone Joint Surg Am* 88(4):698–705. <https://doi.org/10.2106/JBJS.E.00339>
  14. Blazek K, Favre J, Asay J, Erhart-Hledik J, Andriacchi T (2014) Age and obesity alter the relationship between femoral articular cartilage thickness and ambulatory loads in individuals without osteoarthritis. *J Orthop Res* 32(3):394–402. <https://doi.org/10.1002/jor.22530>
  15. Maffiuletti NA, Jubeau M, Munzinger U, Bizzini M, Agosti F, De Col A, Lafortuna CL, Sartorio A (2007) Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *Eur J Appl Physiol* 101(1):51–59. <https://doi.org/10.1007/s00421-007-0471-2>
  16. Himes CL, Reynolds SL (2012) Effect of obesity on falls, injury, and disability. *J Am Geriatr Soc* 60(1):124–129. <https://doi.org/10.1111/j.1532-5415.2011.03767.x>
  17. Bhasin S, Travison TG, Storer TW, Lakshman K, Kaushik M, Mazer NA, Ngyuen AH, Davda MN, Jara H, Aakil A, Anderson S, Knapp PE, Hanka S, Mohammed N, Daou P, Miciek R, Ulloor J, Zhang A, Brooks B, Orwoll K, Hede-Brierley L, Eder R, Elmi A, Bhasin G, Collins L, Singh R, Basaria S (2012) Effect of testosterone supplementation with and without a dual 5alpha-reductase inhibitor on fat-free mass in men with suppressed testosterone production: a randomized controlled trial. *JAMA* 307(9):931–939. <https://doi.org/10.1001/jama.2012.227>
  18. Harrison MM, Morrell J, Hopman WM (2004) Influence of obesity on outcome after knee arthroscopy. *Arthroscopy* 20(7):691–695. <https://doi.org/10.1016/j.arthro.2004.06.004>
  19. Spahn G, Muckley T, Kahl E, Hofmann GO (2006) Factors affecting the outcome of arthroscopy in medial-compartment osteoarthritis of the knee. *Arthroscopy* 22(11):1233–1240. <https://doi.org/10.1016/j.arthro.2006.07.003>
  20. Dervin GF, Stiell IG, Rody K, Grabowski J (2003) Effect of arthroscopic debridement for osteoarthritis of the knee on health-related quality of life. *J Bone Joint Surg Am* 85-A(1):10–19
  21. Fabricant PD, Rosenberger PH, Jokl P, Ickovics JR (2008) Predictors of short-term recovery differ from those of long-term outcome after arthroscopic partial meniscectomy. *Arthroscopy* 24(7):769–778. <https://doi.org/10.1016/j.arthro.2008.02.015>
  22. Rosenberger PH, Dhabhar FS, Epel E, Jokl P, Ickovics JR (2010) Sex differences in factors influencing recovery from arthroscopic knee surgery. *Clin Orthop Relat Res* 468(12):3399–3405. <https://doi.org/10.1007/s11999-010-1562-7>
  23. Kaneko S, Satoh T, Chiba J, Ju C, Inoue K, Kagawa J (2000) Interleukin-6 and interleukin-8 levels in serum and synovial fluid of patients with osteoarthritis. *Cytokines Cell Mol Ther* 6(2):71–79
  24. Brenn D, Richter F, Schaible HG (2007) Sensitization of unmyelinated sensory fibers of the joint nerve to mechanical stimuli by interleukin-6 in the rat: an inflammatory mechanism of joint pain. *Arthritis Rheum* 56(1):351–359. <https://doi.org/10.1002/art.22282>
  25. Ateschrang A, Eggensperger F, Ahrend MD, Schroter S, Stockle U, Kraus TM (2018) Obesity causes poorer clinical results and higher re-tear rates in rotator cuff repair. *Arch Orthop Trauma Surg* 138(6):835–842. <https://doi.org/10.1007/s00402-018-2921-1>
  26. Singer SP, Dammerer D, Krismer M, Liebensteiner MC (2018) Maximum lifetime body mass index is the appropriate predictor of knee and hip osteoarthritis. *Arch Orthop Trauma Surg* 138(1):99–103. <https://doi.org/10.1007/s00402-017-2825-5>