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Weight Loss Changed Gait Kinematics in Individuals with Obesity and Knee Pain

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Abstract

BACKGROUND: Obesity is a mechanical risk factor for osteoarthritis. In individuals with obesity, knee joint pain is prevalent. Weight loss reduces joint loads, and therefore potentially delays disease progression; however, how the knee joint responds to weight loss in individuals with obesity and knee pain is not clear.

RESEARCH QUESTION: To assess the effect of weight loss on knee joint kinematics during gait in individuals with obesity and knee pain.

METHODS: We recruited individuals with obesity (BMI ≥ 35) and knee pain who were participating in a weight loss program which included bariatric surgery or medical management. At baseline before and at 1 year after treatment, participants walked on a treadmill, and their knee joint kinematics were assessed using a dual-fluoroscopic imaging system and subject-specific magnetic resonance imaging knee joint models. Gait changes were represented by change in range of tibiofemoral motion, i.e., excursions in flexion-extension, adduction-abduction, internal-

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AUTHOR CONTRIBUTIONS
JL, GL, and DF contributed to the conception and design of the study. JL, TT, and MC contributed to acquisition of data. JL and DF contributed to data analysis. JL, TT, CL, GL, DF contributed to data interpretation. JL drafted the original article and TT MC GL CL DF revised the article. All authors approved the current manuscript.

external rotation, anterior-posterior translation, medial-lateral translation, and superior-inferior translation during gait.

RESULTS: Twelve individuals with obesity and knee pain completed the gait analysis at baseline and 1 year follow-up. Participants lost on average 10.4 % (standard deviation: 17.2%) of their baseline body weight. Reduction in body weight was associated with increased range of flexion-extension ($r = -0.75$, $p < 0.01$) and decreased range of adduction-abduction ($r = 0.60$, $p = 0.04$) during gait. The reduction in body weight was also associated with self-reported pain decrease ($r= 0.62$, $p = 0.04$); however, the change in pain was not significantly associated with kinematic changes.

SIGNIFICANCE: Weight loss was associated with improved gait kinematics in the sagittal and frontal planes. The change in gait pattern in individuals with obesity and knee pain was not associated with the change in pain given a reduction in body weight.

Keywords

weight loss; gait; kinematics; knee pain; fluoroscopic imaging

INTRODUCTION

Obesity is an established risk factor for the development of knee osteoarthritis (OA), one of the most disabling diseases affecting quality of life [1, 2]. In the US, more than one-third of adults are obese, and one in three obese adults has arthritis[3, 4]. In individuals with obesity, knee pain is highly prevalent [5] and is often thought to be the first symptom of knee OA [6]. For patients with knee OA who are overweight or obese, weight loss is recommended by the American College of Rheumatology (ACR) to reduce joint loads and potentially delay knee OA progression[7–12]. Weight loss is effective in reducing pain and improving function in patients with obesity and knee OA[11, 13–15], and in patients with obesity alone[5, 16–18].

Walking is an important function of daily living and is suggested by the Arthritis Foundation and the ACR for knee OA patients to promote healthy living [7, 19, 20]. This safe exercise is also promoted for individuals with obesity to increase energy expenditure to manage body weight [21, 22]. However, reduced daily walking steps [23] and gait alterations were found in individuals with obesity when compared to healthy counterparts [24–26]. In individuals with obesity and knee pain, gait function is further impaired [23, 27]. While some biomechanical studies have demonstrated that weight loss improves spatiotemporal parameters and kinematics during gait in individuals with obesity [28–31], it is still not clear how weight loss affects knee kinematics of individuals with obesity and knee pain and whether any change in kinematics is more closely related to pain reduction than to weight loss. If there were a relationship between change in kinematics and knee pain after weight loss, then it might suggest that the gait alterations seen represent compensatory gait changes to lessen pain or vice versa.

The instrumentation (i.e., motion capture system) used in kinematic studies may threaten the accuracy of the measured parameters due to the uncertainty of marker placement when the subcutaneous tissue has significantly changed after weight loss [31]. In the past decade, new instrumentation has been developed to measure the kinematics of the knee with higher accuracy and repeatability[32, 33]. This technique uses dynamic X-ray/fluoroscopic imaging to track bone motions directly, instead of capturing the markers on the skin, and then registers the subject-specific magnetic resonance imaging/computed tomography bone models to measure knee kinematics. This technology eliminates the artifacts created by subcutaneous tissue and improves the repeatability of marker placement in 3-dimensional (3D) motion capture systems after weight loss [32, 33].

We applied dual fluoroscopic imaging herein to assess the effect of body weight change on knee kinematics during gait in individuals with obesity and knee pain who were undergoing either bariatric surgery or medical weight loss treatment. We expected a wide variation in weight loss experiences with some participants losing a lot of weight and others experiencing less loss. We focused on the correlation of weight loss, knee pain, and knee kinematics, trying to determine, using this novel technology, what kinematic changes occurred and whether kinematic changes were more strongly correlated with weight loss or pain reduction in a setting in which both were likely to occur. We hypothesized that change in gait kinematics would be associated with the amount of weight loss and change in knee pain.

METHODS

Participants

Participants were recruited from The Nutrition and Weight Management Program at Boston Medical Center. The baseline recruitment period was from February 2014 to August 2015. Inclusion criteria consisted of BMI ≥ 35, knee pain, aching or stiffness on most of the past 30 days, age between 25-60 years old, ability to walk without any assistance, and eligibility for magnetic resonance (MR) imaging. For participants scheduled for surgery, baseline was within 2 weeks prior to surgery. Exclusion criteria included rheumatoid or inflammatory arthritis, and any prior knee surgeries or plan to receive knee surgery during the follow-up period. The study protocol was approved by Boston University School of Medicine Institutional Review Board, and each participant signed a consent form before the study procedure.

To promote weight loss, participants had bariatric surgery or dietary prescriptions (with or without a combination of medications including phentermine, lorcaserin, phentermine/topiramate, bupropion/naltrexone, or liraglutide). The dietary prescription was designed to control the total energy intake (1200-1500 kilocalories/day for women and 1500-1800 kilocalories/day for men) using a high-protein, low-fat diet with meal replacements as substitute meals. All participants were recommended to walk at least 30 minutes/day and perform resistance exercise at least twice a week.

Experimental procedures

Overall knee pain status was evaluated by a self-reported visual analog scale (VAS) rated on a 0-100 scale with the extremes anchored in 0 (no pain) and 100 (worst imaginable pain). We used a 3-Tesla MR machine (Philips, Achieva, Eindhoven, The Netherlands) with a 16-

channel knee coil to acquire high resolution images of the knee (sequence: Proton Density-Weighted (PDW), Spectral Attenuated Inversion Recovery (SPAIR) sequence, FOV: 160mm × 160mm, TR = 1800ms, TE = 30ms, flip angle = 90°, thickness = 1mm, in-plane resolution = 512 × 512). All the MR images were reviewed and manually segmented to construct the 3D subject-specific knee joint models. Participants were asked to walk on a treadmill at 1.5 mph (0.67 m/s) and knee joint motion was captured using a validated dual fluoroscopic imaging system (Philips, BV Pulsera, Eindhoven, The Netherlands) (Fig 1A). This system captured knee motion at 30 frames per second [32].

To determine the position of each bone at each time frame, we created a virtual environment for the two-dimensional (2D) to 3D registration procedure of the subject-specific bone models and the fluoroscopic images (Fig 1B)[32]. Once the projection of the 3D knee model was matched to the 2D silhouette of the corresponding bones in the fluoroscopic images, knee kinematics in six degree of freedom (6DOF), i.e., flexion-extension, adduction-abduction, internal-external rotation, anterior-posterior translation, medial-lateral translation, and superior-inferior translation, were derived based on the coordinate systems of the tibia and femur (Fig 1C). The details of the kinematic calculations were described in our previous article[27].

The participants returned for a follow-up visit 1 year after the baseline visit. We used the same protocol from the baseline visit to evaluate pain status and measure knee kinematics during gait at the follow-up visit. We used the 6DOF range of knee motion (excursion), defined as the maximum minus the minimum values during the stance phase of the gait cycle, to represent the knee kinematics for each visit. We also calculated the changes in spatiotemporal parameters of interests, including stride length, duration of the stance phase, and cadence, to present change in gait characteristics between the two visits.

Statistical Analysis

A paired t-test was used to determine the difference of each variable between the baseline and follow-up visits. Although we technically had no cases and controls, we included both individuals who received bariatric surgery and individuals who received medical management to capture a range of weight loss in our participants (so that some would have more weight loss and others have less weight loss) [34], and we anticipated that this range would allow us to examine the correlations of change in pain and of weight with gait parameters. Pearson's correlation analyses were performed to assess the relationship between the change in range of motion in 6DOF during the stance phase of the gait cycle, change in weight, and change in pain. A two sided significance level was 0.05 for all analyses.

RESULTS

Eighteen participants (15 females and 3 males) completed the baseline visit, of whom 12 (67%) completed the follow-up visit. The participants lost, on average, 10.4% of their baseline body weight (P = 0.05) at follow-up (Table 1). Of the 12 participants with follow-up, 4 had undergone bariatric surgery (mean (standard deviation) weight loss 29.6 (10.9) % of their baseline body weight) and 8 had medical management (mean (standard deviation) weight loss 0.8 (9.9) % of their baseline body weight). On average, knee pain at the follow-up visit was significantly lower than that at the baseline visit (P = 0.04).

In terms of knee joint kinematics, the range of flexion-extension at the follow-up visit was significantly increased compared with the baseline visit (see appendix for 6DOF kinematics). Significant differences between the two visits were also found in internal-external rotation and superior-inferior translation (Table 2). As for the spatiotemporal parameters, the changes in stride length, duration of the stance phase, and cadence between the two visits were 0.5 (11.1) cm, 0.00 (0.10) second, and 0.7 (14.7) steps/min, respectively. None of these changes was statistically significant.

The percentage change in body weight was associated with the change in range of motion in flexion-extension ($r = -0.75$, $p = 0.005$) and in adduction-abduction ($r = 0.60$, $p = 0.04$) during gait (Table 3) such that the greater the weight loss, the greater the increase in both flexion-extension and decrease in adduction-abduction rotation excursion. The percentage change in body weight was associated with the reduction in self-reported VAS pain ($r= 0.62$, $P = 0.04$); however, the change in self-reported pain was not significantly associated with any changes in kinematics (Table 3).

DISCUSSION

We used a novel approach to accurately measure knee joint kinematics during gait before and after 1 year for individuals with obesity and knee pain in a weight loss program. We also tested the association between the changes in gait pattern, body weight, and pain. In general, the participants with weight loss walked with a greater range of flexion-extension and internal-external rotation of the knee joint. Some of the kinematic changes were found to be associated with the change in body weight, but were not associated with change in knee pain severity. To the best of our knowledge, this study is the first to investigate the 6DOF knee kinematics undergoing weight loss.

Our participants demonstrated an increased range of knee flexion-extension during the stance phase of the gait cycle after weight loss, suggesting that weight loss can effectively modify knee kinematics. However, our finding is not consistent with some studies showing that weight loss has no significant effect on knee kinematics during walking [28–31]. For example, Hortobagyi et al. [30] and Vartiainen et al. [31] reported that the knee motion in the sagittal plane (i.e., flexion-extension) in stance phase was not significantly changed after weight loss when walking at a standardized speed. One possible explanation for why our results differ is that the instrumentation used in previous studies was prone to soft tissue artefacts. Instead, our study improved the measurement accuracy by using fluoroscopy technology. Another factor could be the pain status; participants analyzed in our study had pain that was rated as being more severe than individuals analyzed in previous studies [30–31].

Transverse plane motion, i.e., axial rotation, is thought to be a key component in OA development; however, this kinematic outcome is rarely reported in persons with obesity [35, 36]. Our participants demonstrated an increased range of internal-external rotation that could be interpreted as an improvement in motion in the transverse plane, as individuals with obesity and knee pain have been shown to have smaller range of internal-external rotation compared to a healthy group [27]. In addition, the combined effect of an increased range of motion in flexion-extension and internal-external rotation after weight loss may allow for greater distribution of stress at the knee joint during the stance phase of the gait cycle [37, 38]. Although we found that the mean changes in spatiotemporal parameters between the two visits were minimal, the large variation in stride length and cadence suggests that a within-participant difference exists after weight loss. The same participant may adapt to a different stride length and cadence while walking after weight loss.

Our results demonstrated a negative association between the change in range of flexion-extension and the change in body weight, indicating that those participants who experienced more weight loss had more kinematic change than those who did not lose weight. In addition, we found a positive association between the decrease in range of adduction-abduction and weight loss, suggesting stability of the knee may change in the frontal plane after weight loss, as more body sway in the frontal plane is reported in individuals with obesity [26]. This may reduce stresses on the knee through more even distribution of loads between the medial and lateral compartments.

Our results also showed a correlation between the reduction in self-report VAS knee pain after weight loss and change in body weight. This is in agreement with previous studies [5, 17, 39, 40, 41]. Current evidence on pain reduction by weight loss is mostly through bariatric surgery. Vincent et al. [17] showed that knee pain and back pain were rapidly relieved by nearly one-third and more than one-half, respectively, of their pre-surgical pain with ~15% body weight loss in the first three months after surgery. Similarly, Abu-abeid et al. [41] reported that knee pain in patients with obesity was significantly reduced after weight loss of 6.2 BMI units.

Our findings have certain implications for knee OA in individuals with obesity. Based on the three variables in our study, i.e., body weight, knee kinematics, and pain (Fig 2), we found that, for those who lost greater than ~10% of their baseline body weight, the kinematics and pain both changed. Such combined effect of reduced total amount of loads, altered kinematics and pain may enhance the mechanical environment of the knee joint[37]. On the contrary, kinematic and pain changes in those who had consistent body weight did not show a clear tendency for change in kinematics or knee pain. This implies weight loss has both biomechanical and analgesic effects.

Among limitations of our study, the sample was small with higher ratio of females to males. This limited us in performing analysis with adjustment for potential confounders. In addition, we could not randomize participants to surgery. As expected, we found that patients with medical management did not lose much weight nor experience much reduction in pain, and we took advantage of this to create a sample with a broad range of experiences. This broad range made it possible for us to examine correlations of weight loss and pain reduction with change in gait. Our results may not generalize to all persons with obesity, as the BMI in our participants was ≥ 35 at baseline. We did not measure muscular activities using electromyography and ground reaction force data, so the kinematic data could not be further processed to calculate joint moments and estimate the joint force. The fluoroscopy imaging system in this study is designed for treadmill gait and the gait kinematics may not generalize to overground conditions. Despite these limitations, our study has some strengths. We used a technology that significantly improves kinematic measurement error by subcutaneous adipose tissue in obese individuals to track knee motion in a longitudinal study. The high precision in measurement allows us to assess the knee kinematics in 6DOF for individuals with obesity.

CONCLUSION

Weight loss was associated with improved gait kinematics in the sagittal and frontal planes. The change in gait pattern in individuals with obesity and knee pain was not associated with the change in pain. Therefore, weight loss should be addressed in individuals with obesity and knee pain to improve both gait pattern and knee pain.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Weight loss improves knee kinematics during gait in the sagittal and frontal plane
- Weight loss improves knee pain
- The kinematic change after weight loss was not associated with change in pain

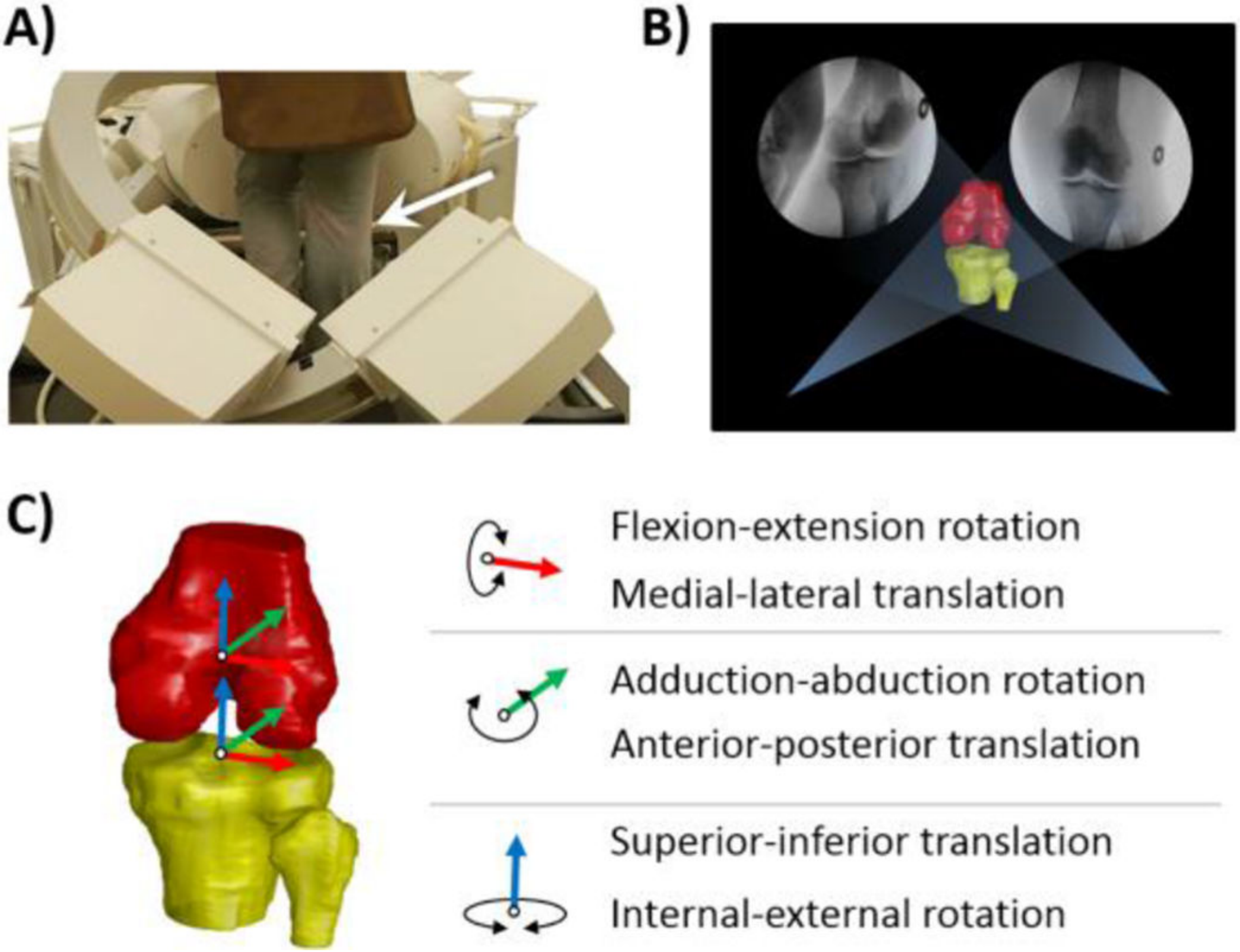

Fig 1.

A) knee joint motion captured using a dual fluoroscopic imaging system ; B) two-dimensional (2D) to 3D registration procedure of the subject-specific bone models and the fluoroscopic images; C) knee kinematics in six degree of freedom (6DOF), i.e., flexion-extension, adduction-abduction, internal-external rotation, anterior-posterior translation, medial-lateral translation, and superior-inferior translation.

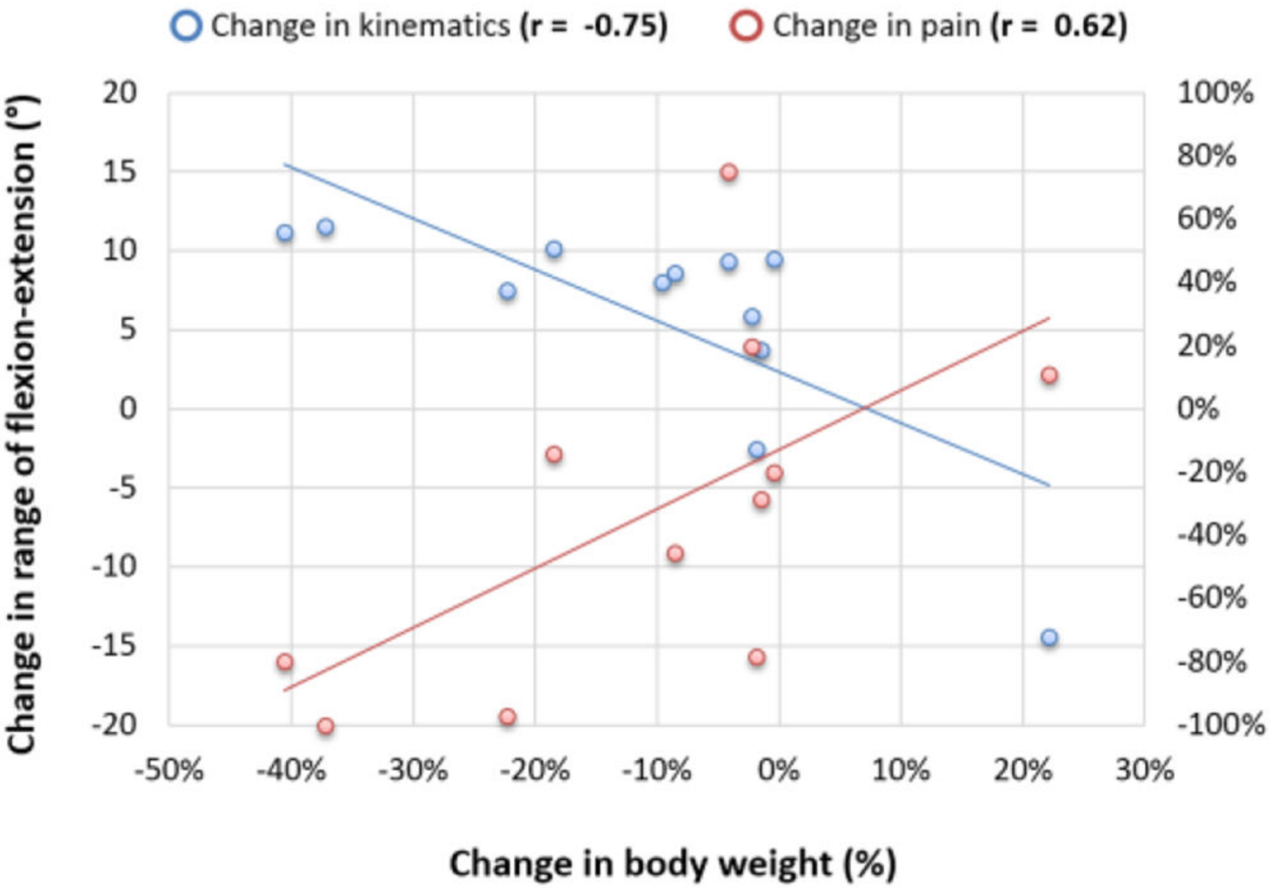

Fig 2.

Illustration of distribution of change in body weight and corresponded body weight and pain changes. Change in each variable is calculated as [follow-up - baseline]

Table 1.

Subject characteristics at baseline and follow-up

	Baseline	Follow-up	P value
Women (%)	75%	–	
Age (years)	45.4 (8.8)	46.5 (8.9)	
Mean Body Weight (kg)	106.0 (12.2)	95.3 (22.2)	0.05
Mean Body Weight change (%)[a]		−10.4 (17.2)	
Mean BMI (km/m^2)	39.0 (2.9)	34.8 (6.7)	0.05
Mean VAS Pain (0-100mm)[b]	64.8 (17.3)	42.0 (31.9)	0.04
VAS Pain change (%)[a]		−32.5 (54.8)	
Mean WOMAC pain (0-20)	10.0 (4.4)	8.1 (7.3)	0.19
Knee OA Kellgren and Lawrence grade	1.2 (0.9)	N/A	
Bariatric surgery/medical management (n/n)	4/8	–	
Mean Body Weight change (%,Bariatric surgery/medical management)[a]		−29.6(10.9)/−0.8 (9.9)	

[a] percentage change was calculated as [(follow-up - baseline)/baseline]

[b] VAS stands for visual analog scale

Table 2.

6DOF range of motion during gait at baseline and follow-up

Range of motion	Baseline	Follow-up	Change	P-value
Flexion-extension	33.8 (5.6)	39.5 (8.0)	5.7 (7.4)	0.02
Adduction-abduction	2.7 (1.4)	3.2 (1.4)	0.5 (1.4)	0.27
Internal-external rotation	7.4 (3.1)	9.1 (3.8)	1.7 (2.6)	0.04
Medial-lateral translation	3.0 (1.2)	2.9 (1.0)	−0.1 (1.2)	0.79
Anterior-posterior translation	6.8 (2.2)	5.8 (2.1)	−1.0 (3.0)	0.26
Superior-inferior translation	1.9 (0.7)	2.6 (1.0)	0.8 (0.9)	0.01

Table 3.

The relationship between weight loss (% body weight change), the change in range of motion during gait, and the change in joint pain.

Change in motion	Correlation coefficient body weight change (%) vs. Motion	P value	Correlation coefficient VAS pain change (%) vs. Motion	P value
Flexion-extension	−0.75	0.005	−0.19	0.59
Adduction-abduction	0.60	0.04	0.36	0.28
Internal-external rotation	0.25	0.43	−0.42	0.20
Medial-lateral translation	0.49	0.11	0.17	0.62
Anterior-posterior translation	−0.08	0.79	0.20	0.55
Superior-inferior translation	0.02	0.94	0.25	0.46

All measurements were calculated as [follow-up - baseline]