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Lower impulsive loadings following intensive weight loss after bariatric surgery in level and stair walking: A preliminary study

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ABSTRACT

Background: There are currently very few of studies which have evaluated the role of bariatric surgery in joint loadings and changes in gait. We wanted to examine how impulsive loading would change level and stair walking in severely or morbidly obese subjects after they had undergone bariatric surgery and weight loss.
Methods: Thirteen female and three male adults aged between 30 and 63 years, cleared for Roux-en-Y gastric bypass, were recruited into this study. All subjects were severely or morbidly obese i.e., body mass index was >35 kg/m^2. The measurement methods consisted of triaxial skin mounted accelerometers and ground reaction force (GRF); conducted at two different predetermined gait speeds.
Results: The average weight loss was 27.4 (SD8.7) kg after 8.8 (SD3.9) months of follow-up period. Most of the absolute GRF parameters decreased in proportion to weight loss. However, medio-lateral GRF parameters decreased more than expected. The general trend in the knee accelerations demonstrated lower impulsive loadings in both axial and horizontal directions after weight loss. We did not observe any significant changes in stair walking.
Conclusions: Weight loss after bariatric surgery not only induces a simple mass-related adaptation in gait but also achieves mechanical plasticity in gait strategy.

1. Introduction

Obesity is the main modifiable biomechanical risk factor for large joint osteoarthritis (OA) [1,2]. Weight loss has been shown to reduce pain and improve hip and knee joint function in patients with OA [3,4]. One biomechanical explanation for these benefits is that there is reduced loading in the lower limb joints [5–7].

Bariatric surgery is an effective method to achieve sustainable weight loss, and it can be considered when adequate exercise and diet programs have failed in patients with a body mass index (BMI) of 40 kg/m^2 or greater [8]. Bariatric surgery (Roux-en-Y gastric bypass, RYGP) has been shown to induce sustainable and substantial weight loss, on average 40 kg weight loss or 14 kg/m^2 BMI decrease, in morbidly obese individuals. Recent studies have shown that the excess weight loss after the RYGP operation has resulted in increased mobility and improved physical function in addition to the other improvements in experienced health-related quality of life [9,10].

The relationship between obese gait biomechanics and weight loss has only recently attracted the attention of investigators. At present, there is no consensus on the benefits of weight loss on joint loadings. A reduction in loadings has been observed after weight loss in compressive and resultant forces and in the knee abduction moment [5,6,11], but nonetheless the effects of sustained weight loss on the progression of OA and symptoms related to biomechanical factors remain to be demonstrated [5]. In contrast, DeVita and Hortobágyi [12] concluded that obese individuals may undergo neuromuscular adaptation, and thus the loadings on the knee joints are not necessarily any higher than those of non-obese persons, especially when the walking speed is freely chosen.

There are currently only two studies [13,14] which have evaluated the role of bariatric surgery in joint loadings. Hortobágyi et al. detected [13] no significant changes in normalized peak knee extensor or peak knee abductor moments in otherwise healthy subjects. They proposed that significant weight loss produces adaptations in the kinematics and kinetics of obese gait related to walking speed, i.e., mechanical plasticity in gait, such as a reorganization of the lower extremity torques. Vartiainen et al. [14] reported that hip and knee moments were reduced in proportion to the weight loss and that step width was reduced after the bariatric surgery at standard walking speeds. In knee OA subjects,

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there is also evidence that extensive weight loss does not modify knee moments [11].

OA may be a mechanically induced disorder in which excessive impulsive forces in the knee joint have been claimed to serve as co-factors in the initiation and progression of knee OA [15–17]. This has been verified in animal studies [18,19]. Joint loading studies to evaluate the effects of weight loss in modern gait analysis have mainly focused on investigations into the actual joint moments [5,6,11,13,14]. However, these techniques do not permit the assessment of impulsive loadings during the initial contact phase whereas skin mounted accelerometers (SMAs) seem to be well suited for investigating impulsive joint loading in knee joints [20–23]. Although SMAs cannot measure the real forces on knee joint surfaces, they are practical for use in clinical gait analysis, because they provide reliable estimates of joint impulsive loading (e.g., initial peak acceleration (IPA)) in a non-invasive manner [23].

The objective of the present study was to examine knee joint impulsive loading in level and stair walking in severely or morbidly obese subjects after they had undergone bariatric surgery and experienced weight loss. The measurement methods consisted of triaxial SMAs (i.e., to determine IPA and peak-to-peak (PP) acceleration) and force platforms (i.e., to determine vertical and horizontal (antero-posterior (AP), and the medio-lateral (ML)) ground reaction forces (GRFs) and maximal loading rate (LR_{max})) conducted at different predetermined gait speeds [22,23].

We examined the two different hypotheses of gait changes based on proposals described by Hortobágyi et al. [13] and our earlier findings [14]. Our first hypothesis was that the weight loss achieved after bariatric surgery causes a simple mass-related adaptation which would result in a reduction in GRFs and LR_{max} in proportion to weight loss. The second hypothesis was that if the hypothesis that weight loss causes simply mass-driven adaptations in gait is valid, then there should not be any observable changes in body accelerations (i.e., IPA and PP acceleration), because body accelerations are not dependent on body mass, and therefore, body accelerations should not change if gait pattern and velocity do not change.

2. Methods

2.1. Subjects

Participants were recruited from the Clinical Nutritional Unit of Kuopio University Hospital, Kuopio, Finland. The entry criteria consisted of patients being cleared for bariatric surgery at Kuopio University Hospital and their willingness to take part in the present study. A previous knee or hip arthroplasty, or other current disabilities of the hip, knee or ankle joint (e.g., fractures, ligamentous instability), were used as exclusion criteria.

This study is one of three parallel studies evaluating the changes in physical function and gait kinetics and kinematics after bariatric surgery and radical weight loss using the same subjects but different methodologies and study objectives [14,24].

Eighteen severely or morbidly obese subjects (15 females, three males) participated in the baseline measurements, which were performed before the bariatric surgery. The follow-up measurements were conducted at 8.8 ± 3.9 months after the RYGP operation. Two subjects refused to participate in the follow-up due to personal reasons. One subject was excluded from analyses because of an inability to complete the tests at predetermined speeds. The characteristics of the 15 subjects who were included into the final evaluation are shown in Table 1.

The standard weight-bearing and lateral radiographs of both knees as well as the pelvis radiographs were taken and evaluated using Kellgren–Lawrence grading [25]. Four of the subjects had mild knee OA (KL2) and one had moderate knee OA (KL3), but none of them had hip OA. The self-reported disease-specific joint pain was assessed using the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index [26,27] for those five subjects who complained of knee pain, Table 1.

Each participant gave written consent to participate in this study after receiving detailed information about the study design. The Ethics Committee of Kuopio University Hospital approved the study design.

2.2. Experimental arrangement

The experimental arrangement consisted of the necessary equipment and protocol to measure synchronously the GRF and accelerations in lower limb in our gait laboratory [22,23,28].

The GRF data was measured using two force platforms (OR6-7MA, Amti Inc.; MA, USA) which were assembled at the same level as the rest of the 10-m long laboratory walkway. The SMA data were collected using the Biomonitor ME6000® T16 (Mega Electronics Ltd; Kuopio, Finland), and low-pass filtered using 165 Hz cut off frequency. The sampling frequency was 1000 Hz for all signals. Walking speed measurements and start trigger generation were obtained using a pair of photo-cells at shoulder level and custom LabVIEW 2010 (National Instruments, TX, USA) software. The photo-cell zone monitored 2.20 m in the middle of the walkway. The experimental arrangement is illustrated in Fig. 1.

One calibrated triaxial piezoresistive SMA (Meac-x, Mega Electronics Ltd; Kuopio, Finland) was attached tightly to the skin below the right knee with a 10 cm wide adhesive bandage (Fixomull stretch) and straps. The positive z-axis a_z was aligned parallel to the straight limb and a_x and a_y axes were parallel to the horizontal directions. The position of the knee SMA was in the medial surface of the proximal tibia at 20% of the distance between the medial malleolus and the medial knee joint space [22,23]. Soft tissue thickness beneath the SMA is generally small at the selected location, regardless of high BMI. Reproducibility and repeatability of knee IPA and PP parameters have been shown to be good [23].

Test subjects walked barefoot in both the laboratory and the stairway. The trial order was randomized in every phase. All subjects were given about 5 min for warm-up and to become familiar with the experimental protocol. In the laboratory, measurements at two constant speeds, 1.2 m/s and 1.5 m/s, were performed. Stair-walking trials, ascent and descent at a constant 0.5 m/s speed along the main axis of the stairway, were performed in an ordinary stairway (12 steps in total, 30° inclination and 26 cm step depth, 1.85 m stair width) [22,23].

A trial was accepted if the speed was within ±5% of the target speed. Laboratory trials were repeated until 6 successful measurements were obtained at each speed. The subjects were instructed to walk naturally at a steady speed and to adjust their speed if the target speed was not achieved. On the stairs, four successful trials, each consisting of four gait cycles, for both directions were conducted.

Table 1
Subject characteristics.

	Baseline (n = 15)	Follow-up (n = 15)
Age	45.7 (30–63)	46.8 (31–65)
Body mass (kg)	125.6 (97.9–172.0)	98.2 (77.9–142.7)
BMI (kg/m^2)	43.3 (36.4–51.2)	33.9 (26.0–42.0)
WOMAC[a]		
Pain (0–100 mm)	21.2 (4.7–42.5)	17.4 (4.9–50.5)
Knee/hip KL-grading[b]		
0	6/14	
1	4/1	
2	4/0	
3	1/0	
4	0/0	

Values are means (range) and knee/hip KL-gradings are number of subjects in each grade.
[a] Those who reported knee pain (n = 5), WOMAC (Western Ontario and McMaster Universities Arthritis Index).
[b] The more severely affected side, Kellgren–Lawrence (KL) grade.