Published in final edited form as:

Gait Posture. 2020 February ; 76: 377–381. doi:10.1016/j.gaitpost.2019.12.020.

Changes in center of pressure velocities during obstacle crossing one year after bariatric surgery

Daekyoo Kim, Simone V. Gill*

College of Health and Rehabilitation Science: Sargent College, Boston University

Abstract

Adults with obesity have atypical gait with poor balance leading to an increase in fall risk. After massive weight loss, their gait improves. However, we know little about changes in postural stability after massive weight loss. The present study aimed to examine how massive weight loss after Roux-en-Y bariatric surgery affected adjustments in center of pressure (COP) velocities during flat ground walking and obstacle crossing. Before and one-year post-bariatric surgery, nineteen female adults walked under four conditions: baseline walking on flat ground and obstacle crossing with three different obstacle heights for a total of 20 trials. COP data were obtained from raw pressure time series data extracted from a gait carpet. Massive weight loss increased anteroposterior COP velocities under the midfoot of both trailing and leading legs ($p < .01$) and decreased mediolateral COP velocities under the forefoot of trailing leg ($p < .05$). Decreased BMI from pre- to post-surgery was correlated with an increase in anterior-posterior and decrease in medial-lateral COP velocities and with increased velocity ($p < .05$). Massive weight loss not only improved gait but also facilitated effective balance control strategies. Examining how massive weight loss affects adjustments in COP velocity may help create ways to better understand why individuals with obesity have atypical gait with poor balance and how we can facilitate participation in physical activities.

Keywords

obesity; gait; bariatric surgery; COP; obstacle

Introduction

Obesity in the United States is a public health concern, resulting in numerous comorbid conditions including heart disease, stroke, type-2 diabetes, and certain cancers that may cause premature death [1]. As of 2015-2016, 39.6% of U.S. adults aged 20 and older were classified with obesity (BMI ≥ 30 kg/m²), but the rates for adults aged 40+ and for women

*Corresponding author: 635 Commonwealth Avenue, Room 501, Boston, MA 02215, simvgill@bu.edu.

Conflict of Interest

The material within has not been and will not be submitted for publication elsewhere. There are no conflicts of interest. All authors were fully involved in the study and the preparation of this manuscript.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

are far higher (42.8% for adults aged 40-59 and 35.7% for adults aged 20-39; 41.1% for women and 37.9% for men, respectively) [2]. One common characteristic of individuals with obesity is atypical gait with poor balance, which increases susceptibility to falls, interferes with daily living activities, and decreases independence [3]. In U.S. adults aged 45-64, the chances of suffering from fall-related injuries are 15% for overweight (25 kg/m^2 BMI 29.9 kg/m^2) to 79% for those with BMI over 40 kg/m^2 compared to adults with normal BMI [4]. Females are more likely to suffer a fall injury; the rates of fall-related injuries among females aged 45-64 were similar to males aged 65 years or above [5]. Thus, obesity and poor balance compound the risk of falls in this population.

Bariatric surgery is a direct way to induce massive weight loss. U.S. adults with obesity have increasingly turned to surgery to lose weight. There were 216,000 weight-loss surgeries performed in 2016, steadily increasing since 2011, with a marked increase of 10% from 2015 to 2016 [6]. Patients who undergo Roux-en-Y gastric bypass (RYGB) surgery report nearly 35% a decrease in body mass [7]. However, massive weight loss alone is not enough to eradicate fall risks. In a study of 167 adults' post-bariatric surgery, 20% fell two or more times after surgery [8]. Continued fall risks may be due to residual deficits in balance that persist even after massive weight loss. This poses a question; is massive weight loss alone enough to improve balance, or do bariatric patients prioritize certain biomechanical parameters to detect and minimize the risk of falling? If so, do those parameters change after bariatric surgery?

To date, a limited number of studies focus on changes in gait after bariatric surgery [9, 10]. Massive weight loss results in changes in gait measures that suggest an increase in walking speed and a decrease in the need to maintain postural stability: increases in gait velocity and step length and decreases in step width and double limb support time. Our recent work suggests that atypical gait linked with obesity is more obvious when meeting an external constraint such as obstacle crossing [11]. In studies showing gait before surgery, adults with obese BMI (BMI $\geq 30 \text{ kg/m}^2$) showed slower velocities, wider step widths, and more time in double limb support during obstacle crossing, compared to adults with normal BMI. After massive weight loss, patients improved all of those gait parameters. However, testing spatiotemporal gait characteristics may only reveal part of the story. For example, other work suggests that there is a correlation between BMI and plantar pressure under the midfoot in women with obesity during flat ground walking [12]. Weight loss reduces peak mediolateral ground reaction force [13] and peak plantar pressures [14, 15]. Moreover, a reduced fluctuation in mediolateral center of mass (COM) and lateral leg swing during level walking after weight loss [16] would have been expected based on a decrease in the mediolateral ground reaction force. Also, the plantar pressures are all associated with an increase in balance.

In the present study, we quantified postural stability by measuring the velocity of the center of pressure (COP): the velocity at which the central point of pressure distribution acting under the plantar surface of the foot travels. The COP velocity captures how quickly the body shifts over each foot during the walking cycle [17]. The COP has been used as an index of postural stability in numerous studies focusing on obstacle crossing [18, 19]. Specifically, the rate of change of the COP is sensitive enough to detect how the motion of

the body's center of mass (COM) changes over a relatively small base of support provided by the feet [20]. Thus, in this study, we examined COP velocity in a group of adults who experienced massive weight loss after bariatric surgery as they crossed obstacles of various heights. We hypothesized that the reductions in BMI would be associated with improvements in postural stability during flat ground walking and obstacle crossing and that improvements in postural stability would be linked with gait parameters. Based on the previous literature on the relationship between BMI and changes in spatiotemporal gait [9-16], we believed that massive weight loss would alter COP velocity.

Methods

Participants

Nineteen female adults undergoing bariatric surgery were recruited from weight management and bariatric surgery clinics at Boston Medical Center (BMC) and Massachusetts General Hospital (MGH) (Table 1). Study eligibility included being between 30-60 years old, having approval for bariatric surgery, a body mass index (BMI) ≥ 35 kg/m², no hip, knee, and foot pain on most days during the past 30 days, the ability to speak and read English, the ability to comply with all study procedures and schedule, and the willingness to give informed consent. The study was approved by the Boston University Institutional Review Board and conformed to the Declaration of Helsinki. Informed written and verbal consent was obtained before testing began.

Equipment

Gait parameters were obtained using GAITRite Electronic Walkway (GAITRite Inc., Clifton, New Jersey, USA). The pressure-sensitive gait carpet (5.25 m long $\times$ 0.88 m wide) measured the distance (x and y coordinates) and timing of each footfall at a spatial resolution of 1.27 cm and a sampling frequency of 120 Hz. Obstacles were made of a wooden dowel (81 cm long and 2 cm in diameter) inserted into two wooden towers (25 cm high). Obstacle heights were changed by moving the dowel to one of three holes located in the towers. Each hole was positioned at 5 cm, 10 cm, and 20 cm to create low, medium, and high obstacles respectively. The heights represented obstacles that participants might face in their everyday environments such as a door threshold, small step, or tall step.

Experimental Procedure

All subjects were tested one year apart in the Motor Development Lab at Boston University. Subjects were tested once before surgery and a year later to adapt to their new weight. Participants walked barefoot at a self-selected pace for a total of 20 trials under four conditions: baseline on flat ground with no obstacle and obstacle crossing with low (5 cm), medium (10 cm), and high (20 cm) obstacles. They began trials standing at the edge of the carpet, and ended trials a few steps after walking off of the carpet. Trials began and ended walking with verbal prompts from the experimenter (i.e., "Go" and "Stop"). For the baseline trial, participants walked on flat ground for five trials at their own pace. For the obstacle trials, participants stepped over obstacles in the middle of the path and walked to the end of the walkway five times (Figure 1). Obstacle height order was counterbalanced using a computer random number generator but obstacles were blocked by height.

Data Processing

The main dependent variables were gait velocity, step length, step width, single limb support (SS) time, double limb support (DS) time, and maximal center of pressure (COP) velocity (how quickly maximum areas of pressure exerted beneath each foot moved during walking) for the trailing and leading foot while crossing obstacle. The COP velocity was classified into three sub-regions under the foot: hindfoot, midfoot, and forefoot. COP data were obtained from the raw pressure time series data extracted from the GAITRite software. Custom software written in MATLAB (R2018a, Mathworks, Natick, MA, USA) was used to process the COP displacement data in a single gait cycle (i.e., a stride) stepping before and after obstacle (Figure 1). Spatiotemporal gait parameters were computed with a set of the x- and y-coordinates of the COP from the heel to toe or from the timing of foot onsets to offsets on the carpet.

Statistical Analyses

Statistical analyses were performed using SPSS (Version 24.0, SPSS Inc., Chicago, IL, USA). Descriptive statistics were obtained to characterize groups. The dependent variables with a normal distribution were expressed as means and standard deviations. A two-way ANOVA with repeated measures was used to determine the effects of surgical sessions (changes in BMI from pre- to post-bariatric surgery) from the first to the last visit, obstacle conditions (low, medium, and high obstacle heights), and their interaction on gait measures. Effect sizes were reported via partial eta squared after p-values, giving 0.01 (small), 0.09 (medium) and 0.25 (large) effects. Post hoc analyses consisted of pairwise comparisons and were subjected to Bonferroni corrections. Pearson's correlation statistic was used to examine relationships between pre-test BMI and gait parameters and COP velocity, changes in BMI (difference score created by subtracting the post- and pre-surgery BMI scores) and gait parameter, and changes in BMI with COP velocities from pre- to post-surgery. Significance was set at $\alpha < .05$.

Results

On average, BMI decreased by 24.76%. BMI pre- and post-bariatric surgery data were available for all participants (Table 1). There were main effects of surgical session on gait velocity ($F(1, 144)=7.62, p<.01, \eta^2=.05$), step length ($F(1, 144)=4.26, p<.05, \eta^2=.03$), step width ($F(1, 144)=19.75, p<.01, \eta^2=.12$), and DS time ($F(1, 144)=12.81, p<.01, \eta^2=.11$). One year after surgery, participants increased gait velocity and step length, and decreased step width and DS time (Table 2). There were main effects of obstacle condition on gait velocity ($F(3, 144)=7.54, p<.01, \eta^2=.14$) and SS time for the trailing foot ($F(3, 144)=42.95, p<.01, \eta^2=.47$) and the leading foot ($F(3, 144)=33.77, p<.01, \eta^2=.41$). Participants increased their gait velocity and SS time for both trailing and leading foot, as the obstacle height increased (Table 3). There were main effects of surgical session on the velocity of COP in anteroposterior direction under the midfoot region of the trailing leg ($F(1, 144)=11.45, p<.01, \eta^2=.08$) and leading leg ($F(1, 144)=9.43, p<.01, \eta^2=.06$) and the velocity of COP in mediolateral direction under the forefoot region of the trailing leg ($F(1, 144)=5.38, p<.05, \eta^2=.05$). One year after surgery, participants increased the anteroposterior velocity of the COP under the midfoot region of both the trailing and leading

leg and decreased the mediolateral velocity of the COP under the forefoot region of the trailing leg (Table 4).

Before surgery, BMI was not correlated with gait variables (all $p>.05$), but it was correlated with anteroposterior velocity of the COP under the midfoot region of the trailing ($r(19)=-.38, p<.01$) and leading leg ($r(19)=-.43, p<.01$; Table 5). After surgery, however, change in BMI from pre- to post-surgery (i.e., BMI difference score) was correlated with increased gait velocity ($r(19)=-.34, p<.05$), increased anteroposterior velocity of the COP under the midfoot region of the trailing ($r(19)=-.50, p<.01$) and leading leg ($r(19)=-.39, p<.01$), and decreased mediolateral velocity of the COP under the forefoot region of the trailing leg ($r(19)=.33, p<.05$; Table 5). One year after bariatric surgery, when patients pushed off the ground with the trailing leg, the more decreased mediolateral velocity of the COP was associated with decreased step width ($r(19)=.26, p<.05$; Table 5). When patients placed the leading leg across the obstacle and supported the entire body weight with one leg, higher increases in the anteroposterior velocity of the COP under the midfoot region of the trailing and leading leg were linked with increased step length ($r(19)=.27, p<.05$ and $r(19)=.27, p<.05$, respectively), increased gait velocity ($r(19)=.23, p<.05$ and $r(19)=.40, p<.01$, respectively), and decreased DS time ($r(19)=-.34, p<.01$ and $r(19)=-.56, p<.01$, respectively; Table 5). However, there were no main effects of obstacle condition on velocities of COP from any region of the foot of both trailing and leading leg (all $p>.05$). There was no interaction between the surgical session and obstacle condition on any of the dependent variables (all $p>.05$).

Discussion

In this study, we examined changes in flat ground walking and obstacle crossing before and one year after bariatric surgery. The results show that massive weight loss affects improvements in gait and adjustments in COP velocity during flat ground walking and obstacle crossing and that the weight loss effect on COP velocity is associated with spatiotemporal gait parameters.

Despite changes in gait and postural stability after bariatric surgery, only a few studies in the literature exist about biomechanical changes in this patient group. Our use of COP velocity was done with the understanding that COP acts as a representation of the path taken by foot pressure [17]. Thus, as more pressure is loaded on the foot, the longitudinal arch and metatarsal heads become prominent during standing and walking, as has been previously demonstrated from peak pressure analysis. Previous studies found increased peak plantar pressure under the midfoot and forefoot in individuals with obesity. Compared to women with normal BMI, women with obesity displayed increases in pressure under the midfoot and forefoot during standing [12]. A recent study also reported that massive weight loss after bariatric surgery resulted in decreased ground reaction forces and decreased pressure in the forefoot during walking [14]. Pregnancy is another physiological state marked by an increase in body mass. For instance, pregnant women increased the mean peak pressure under the midfoot and forefoot during the late stages of pregnancy and returned to baseline after delivery [15]. It is possible that foot pressure is affected differently in obesity due to the different distribution of weight in the body. However, recent work found no differences

between pregnant women and overweight women according to midfoot pressure load [21]. Even healthy young women when walking with additional bodyweight, up to 30% of their total body weight with a weighted vest, increase and subsequently decrease peak plantar pressure especially in the midfoot once the weight is removed [22]. We believe that a decrease in midfoot peak pressure is nontrivial because it implies that there are some benefits to propulsion and smooth change in COP velocity, which may have an impact on gait velocity.

Our findings are supported by previous literature that assumes that decreased peak midfoot pressure is directly beneficial for propulsion. Decreased midfoot peak pressure implies decreased vertical and mediolateral ground reaction forces associated with reduced longitudinal arch collapse. This assumption is reinforced by previous findings of a negative correlation between plantar pressures and gait velocities, indicating reduced longitudinal arch collapse with higher gait velocities after weight loss [23]. Our data suggest that foot pressure parameters may be important factors for determining spatiotemporal gait characteristics following massive weight loss. In our current study, massive weight loss led to increased gait velocity and step length by increasing the anteroposterior velocity of the COP under the midfoot region of both the trailing and leading leg. That is, it is conceivable that the reduction in load on the longitudinal foot arch after massive weight loss may have allowed patients to propel the trailing leg ahead of the obstacle with a rapid forward transfer of the ground reaction force through the midfoot region and then step their leading leg across the obstacle with a longer step to propel the body forward. These findings are supported by the idea that increasing gait velocity is achieved by increasing both cadence and stride length [24, 25], and increasing the anteroposterior velocity of the COP in the midfoot [26].

In addition, massive weight loss is directly beneficial for postural stability. Wider steps and prolonged double limb support are risk factors for predicting falls [27, 28]. In a study of 597 older adults, step width and double limb support time were two of the best predictors of fall risk [27]. In the present study, along with the decreased step width and double limb support time, bariatric patients decreased the mediolateral velocity of the COP, especially, under the forefoot of the trailing foot. Our findings suggest that after massive weight loss, patients not only reduce the load on their foot but also improve the ability to recover from a loss of balance by reducing the mediolateral COP velocity and step width by quickly altering kinematics when stepping over an obstacle. Given less fluctuations in the body's COM and lateral leg swing after weight loss, reducing the load on the metatarsal regions may lead to a decrease in the mediolateral COP velocity of the forefoot when pushing off the ground with the trailing leg. The leading leg can then be placed across the obstacle with a narrower step width to maintain postural stability. Evidence is available to support our findings. For example, the mediolateral GRF significantly decreased along with step width after weight loss, which was consistent with the results of our study in the context of the foot-ground interaction between the ground reaction forces and its application points (i.e., COPs) within the base of support [13]. Therefore, it is possible that the reduction in mediolateral COP velocity under the forefoot of the trailing leg stands out as being an important factor to transfer the COP from one foot to the next during obstacle crossing. In that sense, our findings provide novel and compelling evidence supporting the idea that COP velocity is

indicative of a postural control strategy during gait [29]. However, multiple factors contribute to balance strategies adults use to avoid falls.

To our knowledge, this is the first study to quantify adjustments in COP velocity when negotiating obstacles after massive weight loss. This study was limited to female adults due to the higher rate of females undergoing bariatric surgery in comparison to males [30]. Another limitation is that we tested a relatively small number of patients with different rates or extents of weight loss. Lastly, additional work needs to be done to detect an underestimated mechanism of falls which often happens to patients after bariatric surgery.

In conclusion, massive weight loss results in improved gait and postural stability during obstacle crossing. COP velocity might be an appropriate parameter to identify dynamic balance control during gait. Examining how massive weight loss affects adjustments in COP velocity may help create ways to better understand why individuals with obesity have atypical gait with poor balance.

Acknowledgments

Support: Supported by funds from an R03 AR066344 (Gill, PI).

References

1. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, ... & Loria CM (2014). 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. *Journal of the American college of cardiology*, 63(25 Part B), 2985–3023. [PubMed: 24239920]
2. Hales CM, Carroll MD, Fryar CD, & Ogden CL (2017). Prevalence of obesity among adults and youth: United States, 2015-2016. US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics.
3. Hills AP, Hennig EM, Byrne NM, & Steele JR (2002). The biomechanics of adiposity—structural and functional limitations of obesity and implications for movement. *Obesity reviews*, 3(1), 35–43. [PubMed: 12119658]
4. Finkelstein EA, Chen H, Prabhu M, Trogon JG, & Corso PS (2007). The relationship between obesity and injuries among US adults. *American Journal of Health Promotion*, 21(5), 460–468. [PubMed: 17515011]
5. Verma SK, Willetts JL, Corns HL, Marucci-Wellman HR, Lombardi DA, & Courtney TK (2016). Falls and fall-related injuries among community-dwelling adults in the United States. *PLoS one*, 11(3), e0150939. [PubMed: 26977599]
6. English WJ, DeMaria EJ, Brethauer SA, Mattar SG, Rosenthal RJ, & Morton JM (2018). American Society for Metabolic and Bariatric Surgery estimation of metabolic and bariatric procedures performed in the United States in 2016. *Surgery for Obesity and Related Diseases*, 14(3), 259–263. [PubMed: 29370995]
7. Courcoulas AP, Christian NJ, Belle SH, Berk PD, Flum DR, Garcia L, ... & Patterson EJ (2013). Weight change and health outcomes at 3 years after bariatric surgery among individuals with severe obesity. *Jama*, 310(22), 2416–2425. [PubMed: 24189773]
8. Berarducci A, Haines K, & Murr MM (2009). Incidence of bone loss, falls, and fractures after Roux-en-Y gastric bypass for morbid obesity. *Applied Nursing Research*, 22(1), 35–41. [PubMed: 19171293]
9. Vartiainen P, Bragge T, Lyytinen T, Hakkarainen M, Karjalainen PA, & Arokoski JP (2012). Kinematic and kinetic changes in obese gait in bariatric surgery-induced weight loss. *Journal of biomechanics*, 45(10), 1769–1774. [PubMed: 22633006]

10. Vincent HK, Ben-David K, Conrad BP, Lamb KM, Seay AN, & Vincent KR (2012). Rapid changes in gait, musculoskeletal pain, and quality of life after bariatric surgery. *Surgery for Obesity and Related Diseases*, 8(3), 346–354. [PubMed: 22336495]
11. Gill SV, Walsh MK, Pratt JA, Toosizadeh N, Najafi B, & Travison TG (2016). Changes in spatiotemporal gait patterns during flat ground walking and obstacle crossing 1 year after bariatric surgery. *Surgery for Obesity and Related Diseases*, 12(5), 1080–1085. [PubMed: 27320220]
12. Hills AP, Hennig EM, McDonald M, & Bar-Or O (2001). Plantar pressure differences between obese and non-obese adults: a biomechanical analysis. *International journal of obesity*, 25(11), 1674. [PubMed: 11753590]
13. Bragge T, Lyytinen T, Hakkarainen M, Vartiainen P, Liikavainio T, Karjalainen PA, & Arokoski JP (2014). Lower impulsive loadings following intensive weight loss after bariatric surgery in level and stair walking: a preliminary study. *The Knee*, 21(2), 534–540. [PubMed: 24332832]
14. Bacha IL, Benetti FA, & Greve JMDA (2015). Baropodometric analyses of patients before and after bariatric surgery. *Clinics*, 70(11), 743–747. [PubMed: 26602521]
15. Gaymer C, Whalley H, Achten J, Vatish M, & Costa ML (2009). Midfoot plantar pressure significantly increases during late gestation. *The Foot*, 19(2), 114–116. [PubMed: 20307461]
16. Peyrot N, Morin JB, Thivel D, Isacco L, Taillardat M, Belli A, & Duche P (2010). Mechanical work and metabolic cost of walking after weight loss in obese adolescents. *Medicine and science in sports and exercise*, 42(10), 1914–1922. [PubMed: 20216466]
17. Grundy M, Tosh PA, McLeish RD, & Smidt L (1975). An investigation of the centres of pressure under the foot while walking. *The Journal of bone and joint surgery. British volume*, 57(1), 98–103. [PubMed: 1117028]
18. Chou LS, Kaufman KR, Brey RH, & Draganich LF (2001). Motion of the whole body's center of mass when stepping over obstacles of different heights. *Gait & Posture*, 13(1), 17–26. [PubMed: 11166550]
19. Wang Y, & Watanabe K (2008). The relationship between obstacle height and center of pressure velocity during obstacle crossing. *Gait & posture*, 27(1), 172–175. [PubMed: 17416525]
20. Masani K, Vette AH, Abe MO, & Nakazawa K (2014). Center of pressure velocity reflects body acceleration rather than body velocity during quiet standing. *Gait & posture*, 39(3), 946–952. [PubMed: 24444652]
21. Karadag-Saygi E, Unlu-Ozkan F, & Basgul A (2010). Plantar pressure and foot pain in the last trimester of pregnancy. *Foot & ankle international*, 31(2), 153–157. [PubMed: 20132753]
22. Hotfiel T, Carl HD, Wendler F, Jendrissek A, Heiss R, & Swoboda B (2017). Plantar pressures increase with raising body weight: A standardised approach with paired sample using neutral shoes. *Journal of back and musculoskeletal rehabilitation*, 30(3), 583–589. [PubMed: 28035908]
23. Pataky TC, Caravaggi P, Savage R, Parker D, Goulermas JY, Sellers WI, & Crompton RH (2008). New insights into the plantar pressure correlates of walking speed using pedobarographic statistical parametric mapping (pSPM). *Journal of biomechanics*, 41(9), 1987–1994. [PubMed: 18501364]
24. Kirtley C, Whittle MW, & Jefferson RJ (1985). Influence of walking speed on gait parameters. *Journal of biomedical engineering*, 7(4), 282–288. [PubMed: 4057987]
25. Lelas JL, Merriman GJ, Riley PO, & Kerrigan DC (2003). Predicting peak kinematic and kinetic parameters from gait speed. *Gait & posture*, 17(2), 106–112. [PubMed: 12633769]
26. Fuchioka S, Iwata A, Higuchi Y, Miyake M, Kanda S, & Nishiyama T (2015). The forward velocity of the center of pressure in the midfoot is a major predictor of gait speed in older Adults. *International Journal of Gerontology*, 9(2), 119–122.
27. Verghese J, Holtzer R, Lipton RB, & Wang C (2009). Quantitative gait markers and incident fall risk in older adults. *The Journals of Gerontology: Series A*, 64(8), 896–901.
28. Zuraes K, DeMott TK, Kim H, Allet L, Ashton-Miller JA, & Richardson JK (2016). Gait efficiency on an uneven surface is associated with falls and injury in older subjects with a spectrum of lower limb neuromuscular function: a prospective study. *American journal of physical medicine & rehabilitation/Association of Academic Physiatrists*, 95(2), 83.
29. Winter DA (1995). Human balance and posture control during standing and walking. *Gait & posture*, 3(4), 193–214

30. Young MT, Phelan MJ, & Nguyen NT (2016). A decade analysis of trends and outcomes of male vs female patients who underwent bariatric surgery. *Journal of the American College of Surgeons*, 222(3), 226–231. [PubMed: 26782151]

Highlights

- Gait kinematics were measured after bariatric surgery in 19 adults.
- Weight loss increased anteroposterior velocity during obstacle crossing.
- Center of pressure velocities were correlated with spatiotemporal parameters.

Figure 1.

Depiction of steps analyzed during obstacle crossing task. A) Sagittal view of walking for the leading foot (i.e., the first foot to cross the obstacle) and the trailing foot (i.e., the contralateral foot to cross the obstacle last): trailing leg (shaded in black), leading leg (shaded in grey). B) Top view (x-y plane) of the center of pressure (COP) trajectories of the trailing and leading leg during obstacle crossing: the hindfoot was defined from the point of initial contact until toe liftoff of the contralateral foot (i.e., initial double limb support, iDS, time), the midfoot as the series of points contacting one foot on the ground until the initial contact of the contralateral side (i.e., single limb support, SS, time), and the forefoot as the points of the push off from the ground until the toe is lifted (i.e., terminal double limb support, tDS, time).

Table 1.

Demographics and anthropometric information. Means are listed with standard deviations in parentheses.

Characteristics	Pre-Surgery (N=19)	1-Year-Post-Surgery (N=19)
Age (yr)	44.16 (8.17)	45.16 (8.17)
Height (cm)	165.31 (7.35)	165.31 (7.35)
Body Mass (kg)	116.43 (16.89)	87.9 (20.74)
BMI (kg/m ²)	42.48 (4.63)	31.96 (6.19)

Table 2.

Means and standard errors from the surgical session.

	Surgical Session		
	Pre	1-Year-Post	P-value
Velocity (cm/sec)	69.54 (1.77)	76.44 (1.77)	<i>p</i> <.01
SL (cm)	49.59 (0.67)	51.54 (0.67)	<i>p</i> =.04
SW (cm)	10.98 (0.36)	8.74 (0.36)	<i>p</i> <.01
SS time of trailing leg (sec)	0.55 (0.01)	0.53 (0.01)	<i>p</i> =.27
tDS time of trailing leg (sec)	0.20 (0.01)	0.16 (0.01)	<i>p</i> <.01
iDS time of leading leg (sec)	0.20 (0.01)	0.16 (0.01)	<i>p</i> <.01
SS time of leading leg (sec)	0.49 (0.01)	0.47 (0.01)	<i>p</i> =.11

SL: step length; SW: step width; iDS: initial double limb support; SS: single limb support; tDS: terminal double limb support

Table 3.

Means and standard errors from obstacle condition

	Obstacle Condition				P-value
	No	Low	Medium	High	
Velocity (cm/sec)	80.04 (2.49)	75.25 (2.49)	71.79 (2.49)	64.27 (2.49)	<i>p</i> <.01
SL (cm)	46.30 (0.95)	51.39 (0.95)	52.15 (0.95)	52.41 (0.95)	<i>p</i> <.01
SW (cm)	9.16 (0.51)	9.44 (0.51)	10.28 (0.51)	10.57 (0.51)	<i>p</i> =.16
SS time of trailing leg (sec)	0.38 (0.02)	0.51 (0.02)	0.57 (0.02)	0.68 (0.02)	<i>p</i> <.01
tDS time of trailing leg (sec)	0.19 (0.01)	0.18 (0.01)	0.18 (0.01)	0.20 (0.01)	<i>p</i> =.18
iDS time of leading leg (sec)	0.19 (0.01)	0.18 (0.01)	0.18 (0.01)	0.20 (0.01)	<i>p</i> =.18
SS time of leading leg (sec)	0.38 (0.01)	0.46 (0.01)	0.51 (0.01)	0.58 (0.01)	<i>p</i> <.01

SL: step length; SW: step width; iDS: initial double limb support; SS: single limb support; tDS: terminal double limb support

Table 4.

Means and standard errors of peak COP velocity in each sub-phase of the stance phase during obstacle crossing

Foot	Direction	Sub-Phase	Surgical Session		P-value
			Pre	1-Year-Post	
Trailing	COPV _{xy} (cm/sec)	Hindfoot (iDS)	88.21 (3.06)	90.72 (3.06)	<i>p</i> =.56
		Midfoot (SS)	33.21 (1.21)	38.90 (1.21)	<i>p</i> <.01
		Forefoot (tDS)	81.06 (2.60)	84.02 (2.60)	<i>p</i> =.42
	COPV _x (cm/sec)	Hindfoot (iDS)	24.41 (1.54)	23.83 (1.54)	<i>p</i> =.79
		Midfoot (SS)	5.83 (0.36)	6.36 (0.36)	<i>p</i> =.30
		Forefoot (tDS)	23.44 (1.66)	18.01 (1.66)	<i>p</i> =.02
	COPV _y (cm/sec)	Hindfoot (iDS)	83.22 (3.05)	85.60 (3.05)	<i>p</i> =.58
		Midfoot (SS)	32.30 (1.22)	38.12 (1.22)	<i>p</i> <.01
		Forefoot (tDS)	75.24 (2.45)	76.14 (2.45)	<i>p</i> =.80
Leading	COPV _{xy} (cm/sec)	Hindfoot (iDS)	85.19 (3.15)	93.73 (3.15)	<i>p</i> =.06
		Midfoot (SS)	34.65 (1.09)	39.21 (1.09)	<i>p</i> <.01
		Forefoot (tDS)	85.76 (2.53)	86.12 (2.53)	<i>p</i> =.92
	COPV _x (cm/sec)	Hindfoot (iDS)	22.48 (1.30)	20.26 (1.30)	<i>p</i> =.23
		Midfoot (SS)	5.41 (0.36)	6.30 (0.36)	<i>p</i> =.08
		Forefoot (tDS)	24.55 (1.54)	25.15 (1.54)	<i>p</i> =.78
	COPV _y (cm/sec)	Hindfoot (iDS)	76.31 (3.44)	71.99 (3.44)	<i>p</i> =.38
		Midfoot (SS)	33.94 (1.08)	38.64 (1.08)	<i>p</i> <.01
		Forefoot (tDS)	82.59 (2.36)	79.45 (2.36)	<i>p</i> =.35

COPV_{xy}: absolute velocity of the center of pressure; COPV_x: mediolateral velocity of the center of pressure; COPV_y: anteroposterior velocity of the center of pressure

Table 5.

Correlations between pre-test BMI and gait variables indicated on the left side of the slash, and on the right correlations between changes in BMI and gait variables from pre- to post-surgery

	BMI	SL	SW	Velocity	DS time	COPV _{y,mid,trial}	COPV _{x,fore,trial}	COPV _{y,mid,lead}
BMI	-	-.02 / -.23	.16 / .05	-.06 / -.34*	.01 / .26	-.38** / -.50**	.10 / .33*	-.43** / -.39**
SL		-	.02 / -.11	.73** / .78**	-.51** / -.48**	.38** / .27*	-.16 / -.06	.36** / .27*
SW			-	-.13 / -.04	.39** / .26*	-.19 / -.19	.07 / .26*	-.27** / -.13
Velocity				-	-.82** / -.50**	.68** / .23*	-.11 / -.07	.63** / .40**
DS time					-	-.62** / -.34**	.01 / .16	-.55** / -.56**
COPV _{y,mid,trial}						-	-.02 / -.22	.65** / .39**
COPV _{x,fore,trial}							-	-.23 / .01
COPV _{y,mid,lead}								-

**
p<.01

*
p<.05

SL: step length; SW: step width; DS time: double limb support time; COPV_{y,mid,trial}: anteroposterior velocity of center of pressure under midfoot of trailing leg; COPV_{y,mid,lead}: anteroposterior velocity of center of pressure under midfoot of leading leg; COPV_{x,fore,trial}: mediolateral velocity of center of pressure under forefoot of trailing leg