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Kinematic Analysis of Patients before and after Abdominoplasty

Jack D. Sudduth[1*], Jessica L. Marquez[1], Mackenzie French[1], Christopher Clinker[1], Justin Webb[1], Devin Eddington[2], Paa Ekow Hoyte-Williams[3], Bradford Rockwell[1], Bo Foreman[4]

[1]Division of Plastic Surgery, Department of General Surgery, University of Utah, Salt Lake City, Utah, USA
[2]Division of Epidemiology, Department of Internal Medicine, University of Utah, Salt Lake City, Utah, USA
[3]Department of Surgery, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[4]Department of Physical Therapy and Athletic Training, University of Utah, Salt Lake City, Utah, USA
Email: *jack.sudduth@hsc.utah.edu

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Abstract

Background: Abdominoplasty has consistently been one of the top cosmetic procedures performed each year with a high patient satisfaction rate. Excision of the excess abdominal skin has been shown to reduce low back pain and improve posture. The effects of the excess skin removal would, theoretically, be demonstrated through changes in gait. This study aimed to measure kinematic differences during gait to obtain objective measures for abdominoplasty. **Methods:** Subjects were recruited from a large, academic plastic surgery clinic. Patients were included if they were 18 years of age, able to walk without an assistive device or any hindrance by any existing medical condition, and were scheduled for abdominoplasty. Kinematic measurements were taken before and after surgery using a plug-in-gait marker set, cameras, and a treadmill. Pre- and postoperative measurements were compared and a post-hoc power analysis was created. **Results:** Nine total patients were included in the study. Joint angles before and after surgery demonstrated moderate differences. However, analysis revealed few significant differences for spatiotemporal or kinematic variables. The power analysis demonstrated an inadequate number of patients to detect significance. **Conclusions:** Despite the literature describing subjective and objective improvements following abdominoplasty, we were unable to validate this. Overall, there were noticeable differences in joint angles pre- and postoperatively, though the study is too underpowered to reach statistical significance. This preliminary data shows that if the study was powered through a larger cohort, then more generalizable conclusions could be drawn.

Keywords

Abdominoplasty, Gait, Kinematics, Surgery, Plastic Surgery

1. Introduction

Excess abdominal skin is a common side effect of extensive weight loss from bariatric surgery and dieting. Pregnancy can also have deleterious effects on the female body, leaving the patient with loose skin and abdominal laxity. [1] [2] The excess skin in the lower abdomen, the pannus, is associated with skin infections, lower back pain, hygiene issues, and reduced respiratory function. [3] [4] A large pannus may limit a patient's mobility, which may cause psychological distress, present a barrier to exercise, and subsequently hinder weight loss. [5] Additionally, abdominal wall weakness secondary to rectus diastasis is common after pregnancy, which can impair the efficiency of the abdominal musculature. [6] Removing the pannus is known as a panniculectomy, whereas an abdominoplasty additionally corrects rectus diastasis, both improving abdominal aesthetics [1] [2] [5].

Abdominoplasty has consistently been one of the top cosmetic procedures performed each year and maintains one of the highest patient satisfaction rates for procedures provided by plastic surgeons. [7] [8] A national report on abdominoplasty reported the rate of abdominoplasty as increasing 344% in a seven-year period. [8] Patient-reported outcomes following abdominoplasty and panniculectomy include improved body image, improved quality of life, and reduced low back pain. [6] [9] [10] [11] Excision of the abdominal pannus has been shown to redistribute the patient's weight offloading the spine and chest wall, reducing low back pain, and improving posture. [6] [12] [13] In addition, the rectus plication improves the patient's core strength, further offloading the spinal musculature. In theory, reducing a patient's weight and improving core strength through abdominoplasty would also affect gait. Abdominal musculature is a well-known contributor to balance and stabilization during gait, as demonstrated in stroke patients who have lost control of their abdominal musculature. [14] In analyzing the literature, we have not identified any studies objectively assessing gait changes following abdominoplasty surgery. Therefore, this pilot study aimed to objectively quantify if abdominoplasty influences spatiotemporal and lower extremity kinematics during gait. We hypothesized there would be changes to spatiotemporal and sagittal plane kinematic variables after surgery.

2. Methods

Following IRB approval at an academic hospital, subjects were recruited from an academic plastic surgery clinic. Participants were included if they were over 18 years of age, could ambulate without an assistive device, walk without hindrance by any existing medical condition, and were scheduled for abdominoplasty.

Following informed consent, participants were brought to anoptical motion capture research lab at an academic institution. Demographic data were recorded, including age, sex, height, weight, comorbidities, reason for surgery, degree of rectus diastasis, and anthropometric measurements. Individuals were asked to don tight clothing and instrumented with 61, 14 mm retroreflective markers that defined 15 body segments (head, trunk, pelvis, 2 arms, 2 forearms, 2 hands, 2 thighs, 2 legs, and 2 feet) using a modified Plug-In-Gait marker set (Vicon; Oxford, UK). Subjects were asked to walk on a split-belt Bertec Fully Instrumented Treadmill (Bertec; Columbus, OH) while tethered to a fall restraint system. Once they reached a self-selected walking speed and felt comfortable on the treadmill, marker trajectory data was collected using a ten-camera Vicon motion capture system (200 Hz), and kinetic data were collected using the Bertec Fully Instrumented Treadmill (1000 Hz). The same self-selected walking speed was used for both pre and post-testing data captures. Trajectory and kinetic data were synchronized and recorded using Vicon Nexus 2. Post-processing and extraction of variables were performed using Visual 3D (C-Motion, Inc; Germantown, MD). The same methods were used for both the pre and post-abdominoplasty surgery. Spatiotemporal variables measured included stance time, step length, step time, stride length, and swing time for both right and left legs. Kinematic variables measured included maximum flexion and extension angles of the ankle, hip, and knee during the stance phase and swing phase for both left and right legs, along with pelvic tilt and trunk flexion angles. Data collections were collected preoperatively and minimum of 3 months postoperatively to provide ample time for recovery.

One-sample paired t-tests were used to determine if there was a difference between the pre- and postoperative measurements. A Bonferroni adjustment was applied independently to spatiotemporal and kinematic variables to account for interrelated variables. A power analysis was performed retrospectively based on the Bonferroni adjusted p-values with significance set at 90% power. A $p < 0.05$ was used for all measurements unless otherwise indicated. All calculations were performed using R 4.2.1. (R Foundation; Vienna, Austria)

3. Results

Seventeen subjects were recruited, and preoperative data was collected; however, eight subjects did not return for post-operative testing, leaving nine patients that we were able to collect pre- and postoperative data for **Table 1**. The subjects who did not return for the post-test reported not having enough time to take off work and participate. For the nine patients with complete data, all patients were female with a median age of 49.0 years with a range of 36 - 61. The median BMI was 26.3 ± 5.7. Most patients sought abdominoplasty for improved appearance of their relaxed skin, and two patients additionally desired surgery to improve back pain. The median width of rectus diastasis for the patients was 3.0 ± 5.9 cm. The median number of days from surgery to post-operative testing was 182.0 ± 30.7. The pre- and post-test weight and height was compared for each patient. The median weight change for the cohort was a gain of 5.0 ± 4.1 kg, and the mean height change for the cohort was a gain of 0.5 ± 1.0 cm.

Analysis of pre- and postoperative testing revealed few significant differences for spatiotemporal or kinematic variables (**Table 2** & **Table 3**). The spatiotemporal variables demonstrated no significant difference after abdominoplasty. The

Table 1. Patient demographics.

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8	Patient 9	Median ± SD
Age	61	37	50	30	46	36	49	51	61	49.0 ± 10.8
Sex	F	F	F	F	F	F	F	F	F	
Pre-Test BMI	25.7	26.3	28.3	18.6	24.2	23.7	32.5	33.3	37.3	26.3 ± 5.7
Diabetes	N	N	N	N	N	N	N	N	N	
HTN	N	Y	N	N	N	N	N	N	Y	
Tobacco	N	N	N	N	N	N	N	N	Y; 0.5 PPD	
Reason For Surgery	Improved appearance; back pain	Back pain; improved core strength	Improved appearance	Improved appearance	Improved appearance	Improved appearance	Improved appearance	Improved appearance	Improved appearance	
Width Of Rectus Diastasis (cm)	5	20	1	1.5	3	3	2	4	3	3.0 ± 5.9
Surgery to Post-Test (days)	124	160	207	179	182	208	170	228	195	182.0 ± 30.7
Pre−Test										
Height (cm)	172.5	159.6	159.7	168.5	165.0	168.0	165.0	168.0	150.0	165.0 ± 6.7
Weight (kg)	76.6	67	72.3	52.8	65.9	67	88.5	94	84	72.3 ± 12.9
Post-Test										
Height (cm)	172.7	161.0	159.5	167.5	165.0	168.0	166.0	170.0	149.5	149.5 ± 6.9
Weight (kg)	75.4	66	72	57.3	61.5	64.5	95	89.5	89	89.0 ± 13.7
Difference*										
Height (cm)	0.2	1.4	−0.2	−1.0	0.0	0.0	1.0	2.0	−0.5	0.5 ± 1.0
Weight (kg)	1.2	1	0.3	−4.5	4.4	2.5	−6.5	4.5	−5	−5.0 ± 4.1

*The difference was calculated as the pre-test variable minus the post-test variable; SD—standard deviation.

Table 2. Spatiotemporal variables before and after surgery with power analysis.

	Preop (SD)	Postop (SD)	Difference (SD)	p-value	Power	N required for 90% power
Left Stance Time	0.76 (0.04)	0.77 (0.06)	0 (0.04)	0.736	0.006	175
Right Stance Time	0.77 (0.04)	0.78 (0.07)	0.01 (0.04)	0.615	0.016	81
Left Step Length	0.49 (0.07)	0.49 (0.09)	0 (0.03)	0.83	0.003	426
Right Step Length	0.49 (0.09)	0.49 (0.08)	0 (0.03)	0.739	0.006	180
Left Step Time	0.58 (0.03)	0.58 (0.05)	0 (0.03)	0.833	0.003	444
Right Step Time	0.57 (0.03)	0.57 (0.05)	0 (0.03)	0.853	0.002	568
Left Stride Length	0.98 (0.16)	0.98 (0.17)	0 (0.05)	0.94	0.001	3462
Right Stride Length	0.98 (0.16)	0.98 (0.17)	0 (0.05)	0.956	0.001	6498
Left Swing Time	0.39 (0.03)	0.38 (0.04)	−0.01 (0.02)	0.526	0.032	53
Right Swing Time	0.38 (0.02)	0.38 (0.03)	−0.01 (0.02)	0.275	0.207	21

Table 3. Kinematic Variables Before and After Surgery with Power Analysis. "L" and "R" refer to left and right, respectively. While "Max" refers to the maximum joint angle achieved and "Min" refers to the minimum joint angle achieved, the relevant direction of motion is listed next to each variable.

	Joint Action	Preop (SD)	Postop (SD)	Difference(SD)	p-value	Power	N required for 90% power
Stance Phase							
L Ankle Angle Max	Dorsiflexion	15.1 (3.13)	15.77 (2.7)	0.67 (3.01)	0.525	0.033	53
R Ankle Angle Max	Dorsiflexion	15.65 (2.57)	16.74 (3.37)	1.09 (1.92)	0.127	0.58	13
L Ankle Angle Min	Plantarflexion	−11.15 (4.98)	−11.06 (7.56)	0.09 (3.9)	0.947	0.001	4343
R Ankle Angle Min	Plantarflexion	−11.95 (7.57)	−10.79 (8.19)	1.16 (1.26)	0.024	0.984	8
L Hip Angle Max	Flexion	21.08 (9.3)	23.37 (6.23)	2.29 (8.54)	0.445	0.06	38
R Hip Angle Max	Flexion	20.82 (8.8)	22.1 (7.38)	1.28 (9.58)	0.699	0.008	135
L Hip Angle Min	Extension	−10.54 (12.95)	−7 (9.27)	3.54 (9.54)	0.298	0.175	23
R Hip Angle Min	Extension	−10.43 (11.76)	−8.79 (9.43)	1.63 (8.44)	0.578	0.022	67
L Knee Angle Max	Extension	2.65 (5.18)	−0.96 (4.54)	−3.61 (3.42)	0.013	0.998	7
R Knee Angle Max	Extension	2.63 (4.38)	0.95 (4.73)	−1.67 (5.56)	0.392	0.088	31
L Knee Angle Min	Flexion	−45.95 (3.23)	−50.79 (4.67)	−4.83 (4.09)	0.008	1	7
R Knee Angle Min	Flexion	−46.53 (3.45)	−50.12 (5.6)	−3.59 (4.78)	0.055	0.887	10
Swing Phase							
L Ankle Angle Max	Dorsiflexion	4.53 (2.88)	6.03 (3.76)	1.5 (3.87)	0.279	0.201	21
R Ankle Angle Max	Dorsiflexion	5.03 (3.16)	6.45 (3.55)	1.42 (1.59)	0.028	0.975	8
L Ankle Angle Min	Plantarflexion	−11.58 (5.73)	−11.12 (8.37)	0.46 (4.41)	0.763	0.005	218
R Ankle Angle Min	Plantarflexion	−12.09 (7.81)	−10.5 (8.44)	1.59 (1.18)	0.004	1	6
L Hip Angle Max	Flexion	26.11 (8.33)	27.93 (4.95)	1.82 (7.7)	0.498	0.04	47
R Hip Angle Max	Flexion	24.55 (6.96)	26.11 (6.92)	1.56 (8.85)	0.612	0.017	80
L Hip Angle Min	Extension	3.04 (11.88)	6.91 (8.69)	3.86 (8.07)	0.189	0.38	16
R Hip Angle Min	Extension	3.29 (10.66)	5.53 (9.95)	2.24 (8.12)	0.432	0.066	36
L Knee Angle Max	Extension	4.49 (4.79)	1.21 (3.55)	−3.29 (3.37)	0.019	0.992	8
R Knee Angle Max	Extension	5.24 (4.4)	3.36 (4.87)	−1.88 (5.68)	0.349	0.121	27
L Knee Angle Min	Flexion	−56.74 (3.22)	−60.84 (3.45)	−4.1 (3.67)	0.01	0.999	7
R Knee Angle Min	Flexion	−56.27 (3.31)	−58.61 (4.83)	−2.34 (4.81)	0.184	0.394	16
Pelvic Tilt Max Angle	Anterior Tilt	7.7 (8.67)	8.05 (5.52)	0.35 (8.01)	0.9	0.002	1239
Pelvic Tilt Min Angle	PosteriorTilt	3.66 (8.67)	3.86 (5.42)	0.19 (8.12)	0.944	0.001	4014
Trunk Flexion Max Angle	Extension	8.12 (5.18)	7.04 (6.11)	−1.08 (7.99)	0.697	0.008	132
Trunk Flexion Min Angle	Flexion	4.64 (4.94)	3.23 (5.77)	−1.42 (7.52)	0.587	0.02	71

power analysis demonstrated an inadequate number of patients to detect significance, with the number of patients required to reach 90% power ranging from 21 to 6498. For the sagittal plane kinematic variables, the most significant differences were shown for the right ankle and the left knee. The maximum and minimum right ankle angles during the swing phase were significant ($p < 0.028$, $p < 0.004$, respectively) with a 90% power at an N of 8 and 6, respectively. The same finding was seen in the peak flexion and extension angle during the stance ($p < 0.013$, $p < 0.008$, respectively) and swing phase ($p < 0.019$, $p < 0.01$, respectively) with an adequate N for 90% power. Bilateral hip angles, pelvic tilt, and trunk flexion were not significantly different after abdominoplasty.

4. Discussion

Objectively measuring outcomes following abdominoplasty is a challenging endeavor. Most of the research detailing the benefits of abdominoplasty hinges on subjective data; however, multiple studies show that patients report less back pain and stronger core musculature after their surgery. [12] [13] Some studies have tried to objectify outcomes through quality of life measures, which all have shown significant improvement following abdominoplasty. [10] [11] Even still, this has not been sufficient for many insurance companies to offer coverage for abdominoplasty. [15] Mazzochi *et al.* were able to objectively assess postural changes following abdominoplasty by measuring center of mass and pressure. They demonstrated that abdominoplasty helped to offload the vertebral column and improved posture in their subjects. [6] We also sought to objectively evaluate the differences in gait following abdominoplasty through measurement of spatiotemporal and kinematic variables.

Through our demographic analysis we showed that the median height change amongst the participants was a gain of 0.5 cm. This is potentially due to postural changes from the rectus plication, allowing patients to stand more erect. Additionally, the median weight change was a gain of 5.0 kg. While the mean reflects a net gain in weight, this actually reflects only three patients in the cohort who each gained a substantial amount of weight. The remaining six patients either remained weight neutral or lost weight. Even still, this emphasizes the importance of early mobility and returning to normal activity as soon as it can be tolerated following surgery.

Quantifying the effects of a procedure on gait through kinematic analysis is a well-documented method. [16] [17] [18] Most notably, this method has been used to compare the effects of reduction mammaplasty on gait, which showed significant differences postoperatively. [19] [20] For this study, we were primarily interested in gait, therefore we selected kinematic variables to investigate specific joints that were primarily moving in the sagittal plane since gait is primarily a sagittal plane activity. The spatiotemporal variables were selected to provide an objective measure of the whole body as it moved through space. Investigating frontal and transverse plane kinematics could prove to be useful, but a larger sample size would be required to achieve appropriate power. In the current study, some variables attained statistical significance. However, the significance noted for the right ankle and left knee should be interpreted with caution because these mean differences are quite small (<5 degrees at the knee and <2 degrees at the ankle) and could potentially be a product of soft-tissue artifact and/or slight differences in marker placement between the pre- and post-testing sessions. In addition, the surgical procedure was performed on the abdomen and should have a similar impact on both lower extremities.

Overall, there were noticeable differences in joint angles pre- and postoperatively, though the study is underpowered to reach statistical significance. In Mazzochi's analysis, they were able to show that plication of the rectus musculature resulted in increased posterior pelvic tilt, which resulted in better posture and less reported back pain. [6] We hoped that our initial data would also show these changes to pelvic tilt, but the sample size was too small to reach significance with a number of patients unable to return for testing. This is best demonstrated in the Left Hip Angle Minimum during the swing phase, which is a surrogate for hip extension. This variable approached significance ($p < 0.189$), but post-hoc analysis revealed that the N required for 90% power is sixteen. Since this pilot study only accrued pre- and postoperative data for nine patients, the variable did not obtain statistical significance.

The lack of power from having a small sample size is the most significant limitation of this pilot study. Based on the power analysis, a cohort of fifty patients would provide a much more meaningful analysis. Though each of our study subjects were informed and consented for both and pre- and post-operative testing, almost half of them did not return for testing and no incentives were offered. They all cited they were unable to take additional time off work. In the future, we plan to offer reimbursement to cover any cost of travel to offset the time of work for patients to complete post-operative testing. Also, because of soft-tissue artifacts, our methods were potentially not sensitive enough to detect small changes that result in subjective improvements. Furthermore, this pilot study looked at joint kinematics that revealed some minor differences consistent with other studies, but it was not statistically significant. However, it demonstrated that further study with a larger cohort could produce more meaningful results. At the next stage, we will continue to look at lower extremity kinetics with a larger cohort.

5. Conclusion

Despite the literature describing both subjective and objective improvements from abdominoplasty, this pilot study did not demonstrate any significant differences of abdominoplasty on spatiotemporal or sagittal plane kinematics in a cohort of nine patients. There were, however, trends that may show significant differences with a higher-powered study. Future research will focus specifically on hip and pelvis kinematics with a larger cohort.

Ethical Statement

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study. Additional informed consent was obtained from all patients for which identifying information is included in this article.

Contribution

All authors contributed equally to this manuscript's creation, editing, and approval.

Conflicts of Interest

The authors have no financial disclosures or conflicts of interest for this study.

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