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Reconstructive

Innovative Use of Thighplasty to Improve Prosthesis Fit and Function in a Transfemoral Amputee

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Background: Excess residual limb fat is a common problem that can impair prosthesis control and negatively impact gait. In the general population, thighplasty and liposuction are commonly performed for cosmetic reasons but not specifically to improve function in amputees. The objective of this study was to determine if these procedures could enhance prosthesis fit and function in an overweight above-knee amputee.

Methods: We evaluated the use of these techniques on a 50-year-old transfemoral amputee who was overweight. The patient underwent presurgical imaging and tests to measure her residual limb tissue distribution, socket-limb interface stiffness, residual femur orientation, lower-extremity function, and prosthesis satisfaction. A medial thighplasty procedure with circumferential liposuction was performed, during which 2,812 g (6.2 lbs.) of subcutaneous fat and skin was removed from her residual limb. Imaging was repeated 5 months postsurgery; functional assessments were repeated 9 months postsurgery.

Results: The patient demonstrated notable improvements in socket fit and in performing most functional and walking tests. Her comfortable walking speed increased 13.3%, and her scores for the Sit-to-Stand and Four Square Step tests improved over 20%. Femur alignment in her socket changed from 8.13 to 4.14 degrees, and analysis showed a marked increase in the socket-limb interface stiffness.

Conclusions: This study demonstrates the potential of using a routine plastic surgery procedure to modify the intrinsic properties of the limb and to improve functional outcomes in overweight or obese transfemoral amputees. This technique is a potentially attractive option compared with multiple reiterations of sockets, which can be time-consuming and costly. *(Plast Reconstr Surg Glob Open 2018;6:e1632; doi: 10.1097/GOX.0000000000001632; Published online 12 January 2018.)*

INTRODUCTION

Obesity is a growing health epidemic[1] that uniquely impacts individuals with lower-limb loss.[2] According to the Centers for Disease Control, more than one-third of U.S. adults are obese and more than two-thirds are overweight.[3] Data on obesity rates specific to amputees are not well-defined, but studies indicate that lower-limb amputees may be more prone to weight gain due to changes in body composition postamputation. Due to changes in lipid metabolism, adjusted body mass index (BMI) has been shown to increase 1 year postamputation.[4] Additionally, increases in the frequency of obesity progression have been found to correlate with the level of muscle atrophy of the residual limb[5] and the level of amputation,[6] making individuals with transfemoral amputation more susceptible to increases in body fat. Much of this excess fat has been noted in

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The research protocol for this study was approved by the Northwestern University Institutional Review Board (STU00090292). Further documentation supporting our informed consent procedures can be provided upon request.

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the form of subcutaneous fat. Although some multifactorial studies have claimed obesity does not statistically correlate with poorer prognosis,[7,8] newer studies examining obesity indicate high BMI levels as a contributing factor to many functional challenges. Such difficulties include decreased prosthetic fit rates,[9] prosthetic use,[4] and ambulatory (K) levels.[2]

While weight loss is encouraged by treating physicians, long-term results are difficult to achieve as exercise is made difficult by the loss of the extremity.[4,10] As an alternative for improving prosthetic fit, alteration of the limb with either direct excision or suction-assisted lipectomy (liposuction) has been suggested but rarely documented. Our search results yielded only 1 report in this context, a case study of 2 transfemoral amputees in which the procedure greatly reduced thigh size, and through observational commentary, improved prosthetic fit.[11] The results appeared promising and sustained, showing reduced thigh size 2 years postsurgery. However, to understand and validate such interventions in a functional context, the combination of a surgical procedure with pre- and postsurgery biomechanical and clinical outcomes analyses is necessary. The objective of this study was to investigate the socket-residual-limb mechanics pre- and postsurgery of a transfemoral amputee with excess thigh fat who underwent a thighplasty and liposuction.[12] Additional outcome measures included the Four Square Step Test, Five Times Sit-to-Stand Test, 6-Minute Walk Test, and 10-Meter Walk Test.[13–16] We hypothesized that the thighplasty and liposuction would reduce excess subcutaneous fat in the residual limb, thereby increasing soft-tissue stiffness and enhancing the patient's prosthetic fit and function. To the best of our knowledge, this study is the first to demonstrate the potential of using a thighplasty with liposuction to improve the quality of life and function for persons with amputation who are overweight or obese and experience poor socket fit.

PATIENTS AND METHODS

Study Participants

Following approval from the Northwestern University Institutional Review Board (IRB), we recruited a 50-year-old Hispanic female. The patient had a right transfemoral amputation over 35 years ago secondary to osteosarcoma. At the time of the study, she was in good health and a K3 ambulator (i.e., able to walk in the community without an assistive device).

The patient was 164 cm tall and weighed 70.57 kg (155.6 lbs.) without her prosthesis (Fig. 1A, B). This yields a BMI of 26.2. If one accounts for the mass of her lost leg, her adjusted BMI was 29.0[17]—close to the borderline for being classified as obese. Much of her excess fat was in her thighs as quantified by pre- and postimaging. She also had a considerable amount of subcutaneous fat at the end of her limb and an irregularity in her amputation scar (Fig. 1A, B).

The patient was chosen because her thigh fat deformed with pressure, causing the proximal brim of the prosthetic socket to slide into her groin. She used an ischial containment suction socket with a C-Leg knee and a Trias prosthetic foot (Ottobock, Inc., Duderstadt, Germany), but she could only wear her prosthesis for 2–6 hours per day before experiencing significant discomfort. The dimension of her residuum was so great that she had a lot of movement between the socket and ischial tuberosity through the soft tissue, causing friction burns with her skin-fit socket. Although other suspension systems may have relieved some of this rubbing, the proximal circumference of her limb was so large (> 60 cm, the clinical cutoff for an Össur seal-in liner) that she was unable to use other commercial suspension systems.

Presurgery the patient completed several imaging and functional assessments. Magnetic resonance imaging (MRI) of both her legs quantified the size of all tissue compartments. X-ray images were taken while the patient was standing with an instrumented pylon and subischial suction fit test socket, to perform the biomechanical analysis for the stiffness of her residual limb while wearing a socket. The stiffness was defined as the patient's volitional loading of her limb in all planes as a function of relative femur displacement.[16] Force and moment levels were held steady during each trial using visual feedback graphically displayed from the load cell and correlated with X-ray images of femur displacement.[18] A sub-ischial socket was chosen because compared with an ischium containment socket, it does not use any bony prominences as a constraint and is thus uninfluenced by any socket-bone resistance. Finally, the patient completed several clinical outcome measures, including the Four Square Step Test, Five Times Sit-to-Stand Test, 6-Minute Walk Test, and the 10-Meter Walk Test.[13–15]

Surgical Procedure

Following presurgery testing and imaging, a thighplasty as described by Lockwood[12] was performed under general anesthesia using standard of care techniques. The procedure was modified to prevent scars from developing along areas of known socket pressure points. The patient was marked both supine and upright, using a standard pinch test to estimate how much skin and subcutaneous fat could be safely removed with an acceptable amount of tension. Under general anesthesia, tumescent solution (50 cc of 1% lidocaine with epinephrine in 1 liter of 0.9 NS) was injected throughout the residual limb to minimize bleeding circumferentially around the thigh, but generally avoiding the area of skin to be removed. Liposuction was performed using a power-assisted liposuction system and an exploded 4 mm cannula circumferentially around the limb; a total of 2,042 milliliters of pure fat was removed. With the limb

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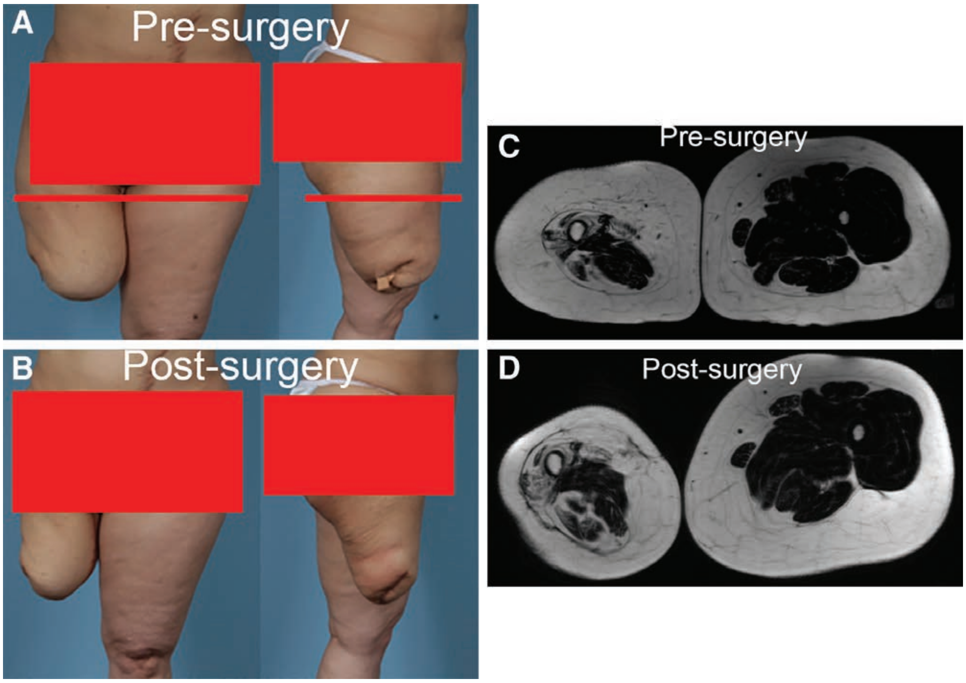
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Fig. 1. Surgical and MRI images. (A and B) Pre- and post- surgical photographs of the patient. The limb became narrower and a bit shorter as distal tissue was removed. (C and D) Pre- and 5-month postsurgical MRIs captured mid-length of the residual limb at the level shown with the red bar.

being decompressed with liposuction, the posterior of the medial thigh incisions was made and carried down to the fascia of Scarpa with a PEAK PlasmaBlade device (Medtronic, Dublin, Ireland). Confirmatory pinch tests were again performed before making the more anterior of the elliptical incision. The incision was extended to the end of the residual limb to remove subcutaneous fat distally within the surgical "dog-ear" as well as to significantly remove the irregular distal scar. The surgical team removed 772.5g of tissue (subcutaneous fat and skin) during the medial thighplasty, for a total of 2,812 g (6.2 lbs.). The skin was drawn together to allow appropriately tight skin around the thigh, and the wound was closed in layers over 2 Axiom CLOT STOP drains (Vitalcor, Inc., Westmont, Ill.) with 2-0 polydioxanone sutures to quilt the deep tissues into approximation to the deep fascia, 3-0 polyglactin suture for the deep dermis, and a stapled skin closure. A snug residual limb shrinker sock was placed around the limb in the operating room following the procedure. Postsurgical swelling was surprisingly limited. The patient's limb continued to slowly shrink as the liposuction-associated swelling resolved.

Postsurgery Testing

Imaging was repeated 5 months after the surgery, and the same functional assessments done presurgery were repeated 9 months postsurgery to assess prosthetic fit and functional differences. The 9-month follow-up timeframe allowed the limb adequate time to stabilize and be fit with a definitive socket. It is also consistent with literature indicating that a patient takes on average 18 weeks to acclimate to newly prescribed prosthetic componentry.[19] An additional postsurgery X-ray was also obtained 9 months after surgery once the patient was fit with the definitive socket.

RESULTS

The appearance and the subcutaneous fat envelope of the residual limb clearly changed (Fig. 1). Photographs of the patient, imaging, and analyses (Figs. 1–3) show that the limb became thinner by ~38%, 50%, 38%, and 27% in the anterior-medial, anterior-lateral, posterior-lateral, and posterior-medial compartments of her limb, respectively (Fig. 2). Her limb was also 13% (30 mm) shorter as distal soft tissue was removed. The reduction of fat can be appreciated when comparing the volume change of the presurgical light blue outline to the postsurgical dark blue outline. Standing X-ray analysis of the femur position showed a more vertical orientation postsurgery, which is a more anatomically appropriate posture (Fig. 4).[20] In her ischial containment socket, the femur angle relative to the vertical axis was reduced from 8.13° to 4.14°. In a sub-ischial containment socket, the femur angle was reduced from 6.81° to 2.09°. All these parameters indicate better limb containment and femur control, which are clinically important factors for proper prosthetic fitting and comfort. Results also indicated a large increase in the socket-residual limb stiffness in 3 of 5 directions: axial 47.3%, medial frontal 63.1%, and anterior sagittal 82.2%. Posterior sagittal had an increase of 6.8%; the anterior-lateral direction had a decrease of 10.7% (Table 1).

The patient's comfortable walking speed increased from 51.9 m/min to 58.8 m/min, a 13.2% improvement. Her stride length increased from 1.17 m to 1.29 m (10.3%).

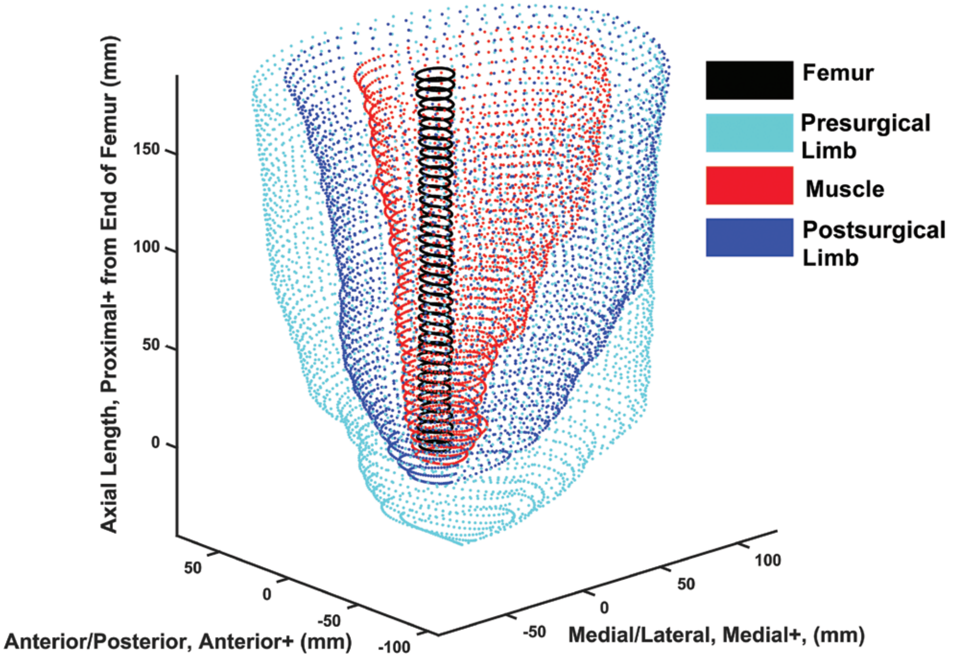

Fig. 2. Volume meshes. 3D volume meshes of the residual limb femur, muscle and pre- and postsurgical limb outer surface, highlighting changes in the limb as a result of fat reduction.

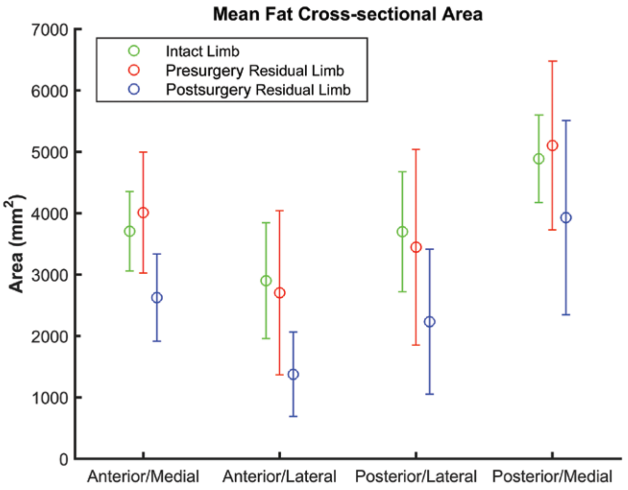

Fig. 3. Cross-sectional area of fat tissue. Plot showing mean and SD of the cross-sectional area of fat tissue (pre- and postsurgery), computed over the length of the residual limb in four compartments of the limb from the MRI data. The intact (sound) limb is shown as a baseline.

Further, all clinical outcomes testing pre- and postsurgery showed improvements (Table 1: longer distances or less time), except that fast walking velocity during the 10-Meter Walk Test remained unchanged. However, the patient could walk 11.4% (an increase of 41.6 meters) further during the 6-Minute Walk Test, which is a measure of aerobic capacity/endurance.[21] This difference is within the recommended Minimally Clinically Important Differences (MCIDs) referenced for the stroke population, which is a 34.4-m change when completing the 6-Minute Walk Test.[22]

Also of important note, the patient reported higher satisfaction in nearly all categories of a questionnaire (Table 2). She reported that her socket fits better, was more stable and comfortable, and that she could walk better. She noted that she could wear her prosthesis for 10–12 hours per day, compared with only 2–6 hours per day presurgery. She was also pleased that her residual limb, with her socket on, became thinner than her sound limb. This improved the cosmesis as well as the fit of her clothing, and she commented it was easier to put on pants. Finally, the patient's leg became small enough in diameter that she was able to use an alternative technology, an Iceross Seal-In liner from Össur (which was not used in this study), in her definitive postsurgical socket (**see document,** Supplemental Digital Content 1, which shows the Thighplasty procedure for improved prosthesis fit and function, ***http://links.lww.com/PRSGO/A649***).

DISCUSSION

Currently, the majority of research aimed at improving the mobility of amputees is directed at designing higher functioning prosthetic devices. These research efforts have yielded some exciting advancements in prosthetic signaling and componentry.[23–25] However, the mechanical properties of the residual limb-socket interface can both enable and constrain prosthesis function, regardless of how well a device may be designed. Socket technologies have had some improvement in materials and suspension, but the socket-limb interface still contributes to the majority of symptoms reported clinically as a result of using prostheses. These symptoms largely include pain, wounds, and infections.[26–28] Symptoms often are amplified with overweight and obese patients, as

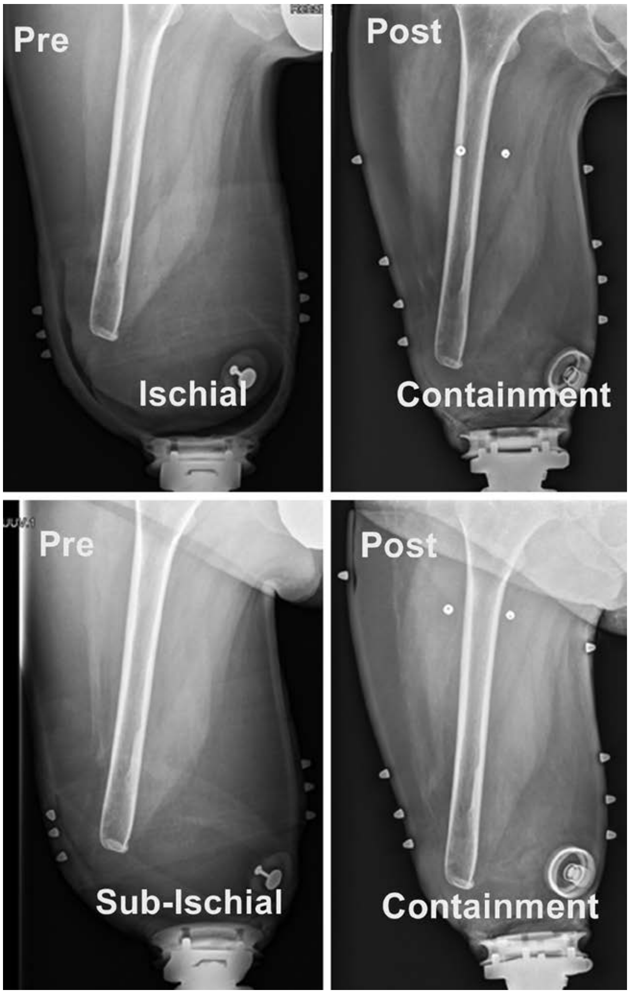

Fig. 4. Femur alignment. Pre- and postsurgical femur alignment in an ischial and sub-ischial containment socket.

there is more relative movement of the tissues with respect to the socket.[29–32] Clinically, excess adipose tissue and weight gain also places restrictions on prosthetic componentry that can be used and makes donning and doffing the prosthesis in the setting of a redundant soft-tissue envelope more difficult.[33–35]

In the context of surgical treatments for amputees, amputation surgery is first performed with the goal of removing all unhealthy or infected tissue while also salvaging as much healthy tissue-bone as possible and reconstructing an effective residual limb.[36] Revision surgeries, such as soft-tissue removal, bone remodeling, or grafting techniques, may be performed after the initial surgery to reduce pain or to improve prosthetic fit. Newer techniques, such as the use of allografts or osseointegration, may provide amputees with more options to increase functionality but have high complication rates and are rather invasive procedures. In the case of osseointegration, which is not yet routinely performed in the United States, greater functionality may be achieved but infections due to the chronic open wound created from the implant remains an unresolved issue.[37] As another example of a surgery targeting amputee function, Targeted Muscle Reinnervation involves the transfer of nerves to increase the number of control sites available for persons who use myoelectric prostheses.[38] All these procedures, however, do not specifically target amputees who experience prosthetic fitting complications due to excess fat in the residual limb.

This study further shifts the focus in the field of prosthetics and amputation rehabilitation from devices to the human—an area with significantly less research to date. Exploring how changing the human residual limb can better interface with technology becomes all the more palatable when the procedure is technically facile and with a low complication profile, which are key characteristics of a thighplasty surgery. In this study, we removed excess subcutaneous fat from the residual limb of a transfemoral amputee to not only make her limb thinner but also to improve the fit and function of her prosthesis. Compared with the previous study reported, we removed nearly 3 times greater of fat.[11] By removing excess soft tissue and fat, the patient developed a firmer limb with a better shape, and a better "bony lock" in her new ischial containment socket, which helped reduce motion in her socket. The thighplasty procedure also reduced the circumference of her residual limb so she could use a different suspension method, a liner that reduced friction on the skin, increasing her overall comfort. In her final socket, the patient could now use a gel liner suction socket, which provides a

Table 1. Clinical Outcomes

A.Clinical Outcome	Presurgery	Postsurgery	Percentage Improvement
10-Meter Walk Test (comfortable, m/s)	0.76	0.80	5.3
10-Meter Walk Test (fast, m/s)	1.01	1·01	0
6-Minute Walk Test (ft.)	1,202	1,339	11.4
Five Times Sit-to-Stand Test (sec)	17.11	12.88	24.7
Four Square Step Test (sec)	9.80	7.73	21.1
Four Square, half prosthesis inside (sec)	4.62	3.21	30.6
Four Square, half prosthesis outside (sec)	4.78	3.54	26.1

B.Direction (units)	Presurgery	Postsurgery	Percentage Improvement
Axial (N/mm)	19 (0.81)	28 (2.9)	47.3
Frontal, medial (Nm/rad)	160 (6.5)	261 (13)	63.1
Frontal, lateral (Nm/rad)	610 (38)	545 (38)	-10.7
Sagittal, anterior (Nm/rad)	170 (5.0)	310 (20)	82.2
Sagittal, posterior (Nm/rad)	470 (20)	502 (13)	6.8

(A) Pre- and postsurgery clinical outcomes. (B) Pre- and postsurgery axial and rotational socket-limb stiffness of the patient.

Table 2. Patient Questionnaire

Patient Question	Pre	Post	Change
Is your socket easy to put on?	1	1	0
Is your socket comfortable while seated?	2	1	1
Is it easy to go from sitting to standing in your socket?	2	1	1
Are you able to wear your socket for long periods of time?	3	1	2
Do you feel stable on your prosthesis with this socket?	3	1	2
Do you like the look/shape of your socket?	7	5	2
Is your socket painful to wear?	3	7	4
Does your socket affect your ability to walk in your home?	3	7	4
Does your socket affect your ability to walk in the community?	3	7	4
Does your socket affect the distance you can walk in the community?	1	7	6
Do you feel you have good control of your prosthesis with this socket?	7	1	6

1–7, 1 = strongly agree; 4 = neither agree nor disagree, 7 = strongly disagree.

layer of cushion and reduces the forces of gait. This surgical option has been reported only once before, with much less total fat removal.

Several other positive practical and functional outcomes were also noted. Her residual limb with her prosthetic socket on was smaller than her normal leg. This was greatly appreciated by the patient for the cosmetic result, as it was easier for her to don pants with the thinner leg. There was also now room to add padding to prevent the hard socket from wearing through her clothes as fast. Additionally, the postsurgical shape of her residual limb became more conical. This enables better loading of the amputee's body weight onto the prosthesis than a cylindrical or bulbous limb. The latter shapes require most of the limb loading to be at the bottom of the leg and the vertical sides to bear little weight. The conical shape enables the load to be transmitted more effectively through all the tissues and it better captures the distal femur.

The magnitudes of the improvements shown in the pre- to postsurgical functional outcomes data were notable. The postsurgical shape of the patient's limb better captured the distal femur in terms of stability and limb control. For example, the Five Times Sit-to-Stand Test and all variants of the Four Square Step Test showed improvements of greater than 20%. MCIDs for these tests for persons with amputation have not yet been established.[39,40] However, the recommended MCID for the Five Times Sit-to-Stand test for patients with balance dysfunction such as vestibular disorders is a difference greater than or equal to 2.3 seconds.[41] This patient was able to complete the Five Times Sit-to-Stand Test 4.23 seconds faster than before surgery. Further, as these tests rely heavily on stability and limb control, a 20% change suggests that the patient may be better able to complete activities of daily living. For example, the patient's dynamic balance and ability to step over objects forward, sideways, and backward are assessed with the Four Square Step Test. The postsurgical results suggest that she may be better able to ambulate within the home and community, specifically in relation to activities of daily living such as toileting and kitchen tasks.[42]

We believe that there are 2 primary reasons for these outcome improvements. First, there was better containment of the femur, as shown by the improvement of the femur angle. The end of the femur aligned closer to the end of the socket, and the distal residual limb became more tapered. Having less subcutaneous fat at the residual limb may also reduce pistoning, decrease the allowable range of movement of the femur, as well as the vertical displacement possible, within the socket. These changes effectively make the residual limb a better lever arm for transferring sagittal and coronal forces between the patient and the prosthesis. Second, removing subcutaneous fat increased the overall socket-residual limb stiffness, as shown in our data. Thus, less distal subcutaneous fat may also decrease the angular and vertical displacement of the femur for a given amount of limb loading. Our outcomes data support the idea that both of these mechanisms were improved via this surgical intervention and consequently enabled a better interface to the patient's residual limb.

Although liposuction and a thighplasty are commonly performed to increase cosmesis, the procedure is not without risks as with any surgery. The risks primarily include the standard elective surgery risks on a limb, which include bleeding, infection, limb edema, undercorrection or overcorrection, and complications from anesthesia. Although this study represents a promising initial evaluation, further work is needed to examine if these results are repeatable and with an increased number of patients to determine statistical significance. We also need to learn more about how to optimally reshape a residual limb with these techniques.

CONCLUSIONS

Data from this study suggest the unique potential of using the thighplasty procedure geared specifically for improving fit and function in transfemoral amputees who experience poor socket fit due to excess fat. By reducing the subcutaneous fat in the residual limb of an overweight transfemoral amputee, our patient demonstrated marked improvements in prosthetic socket fit, biomechanical analyses, and clinical outcomes measures. With further evaluation, this research could improve current clinical care for many amputees. Finally, this study also highlights the importance of performing fit and function analyses, when applicable, following soft-tissue reconstruction surgeries.

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