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Low-Profile Scapulothoracic Bracing: A Case Study on Orthotic Intervention in Chronic Serratus Anterior Palsy

A Novel Slip Torque Closure System to Enable Pressure Regulation in Pectus Carinatum Orthoses

Adjustable Sockets Yield Positive Results

Maintaining Fiber Integrity, Reducing Waste, and Maximizing Design Flexibility During the Fabrication of a Transfemoral Flexible Socket-Rigid Frame: A Discussion of Void Content

Then and Now: Dilatancy O&P Technology and Its Application for Prosthetic Socket Duplication

American Academy of Orthotists and Prosthetists

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ADJUSTABLE SOCKETS YIELD POSITIVE RESULTS

Adjustability within a prosthetic socket is one approach to help patients adapt to residual-limb volume fluctuations. Regardless of the cause of amputation, the shape of a residual limb will change during the initial post-operative period and may continue to change throughout the user's life depending on the patient's weight and residual-limb volume changes. Volume fluctuations influence comfort and stability within the prosthetic socket and an individual's quality of life.[1]

Adjustable sockets allow users to change the shape of the socket to match the shape and contours of their limbs as they change throughout the day or for various situations. Adjustable sockets are beneficial because they make donning easier, accommodate daily residual limb volume fluctuations, and reduce pressure in areas that are sensitive as the wearer becomes more active. Adjustable sockets were developed to allow users to independently change the fit of their prostheses throughout the day without taking them off to add or subtract socks. The ability to adjust a prosthetic socket can also increase suspension and stability during ambulation.[2]

Multiple adjustable systems are available commercially, including LIM Innovations' Infinite Socket, CJ Socket Technologies' CJ Socket, Martin Bionics' Socket-less Socket, and Click Medical's BOA system. In this case series, custom adjustable sockets using the Click Medical BOA Closure system are described. Information was collected on six individuals in this clinical care facility, including outcome measures with the conventional non-adjustable socket and the alternative adjustable socket design. The outcome measure data demonstrates the benefits of adjustability to quality of life (QOL). QOL outcome measures were collected using the OPUS Health Quality of Life Index (OPUS HR-QOL). Balance confidence scores were measured using the Activities-Specific Balance Confidence Scale (ABC). Functional mobility was evaluated using the Prosthetic Limb User Survey of Mobility (PLUS-M) score. Each case presented below demonstrates variations on adjustable designs based on the individual's presentation and his or her needs. The goal of this paper is to share findings from this clinic on how alternative socket design methods can improve an individual's QOL and function.

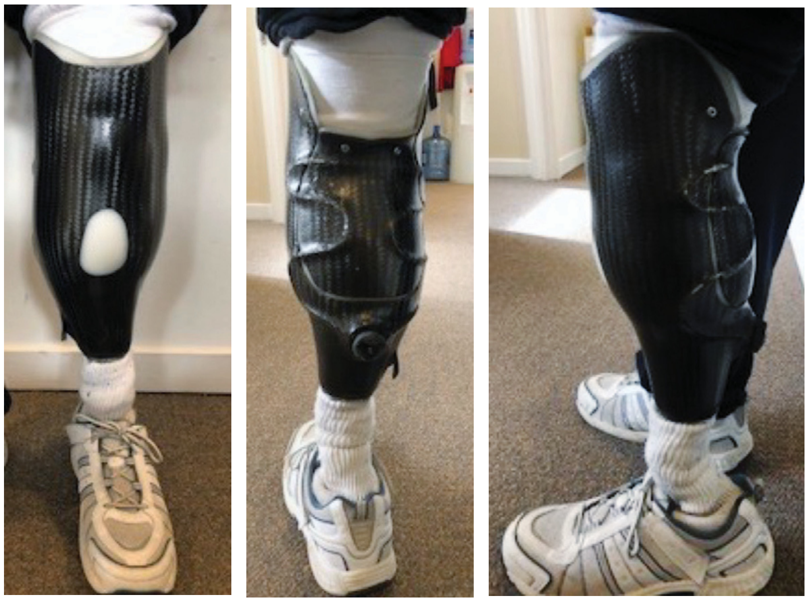


Figure 1. Anterior, sagittal, and posterior view of a left transtibial socket with an adjustable posterior panel.

Table 1. Case 1 outcome measures comparing the conventional socket to the alternative adjustable socket.

Outcome Measures	Conventional Socket	Adjustable Socket
OPUS HR-QOL	52.15	57.6
ABC	48.8%	83.1%
PLUS-M	45.8 (33.7%)	59.6 (83.2%)

Case Reports

Transtibial Socket Designs

Case 1 describes a 67-year-old male who presented with a left transtibial amputation secondary to vascular disease. He became more active after his amputation. He plays wheelchair basketball and walks a few miles per day. He has a bulbous residual limb and was having significant difficulty donning his prosthesis, which featured a standard foam inner socket design to accommodate the volume of his limb. Based on his activity level, his aggressive ambulation, and his weight (over 250 lb.), it was determined that a more robust tunneling system was needed to hold the posterior panel to the socket and create the greatest stability. The tunnels crossed the medial and lateral edges three times.

After approximately six months of wearing the prosthesis, the thread on the BOA Closure System broke, causing the posterior panel to be non-functional. Due to this breakage and natural post-amputation residual limb volume changes, the posterior door was made into a panel; a proximal strut connected the medial wall to the lateral wall. The strut would provide some support on the proximal posterior aspect of the socket, allowing the patient to ambulate more safely if the issue ever repeats. Outcome measures were collected to compare the patient's older conventional socket and the adjustable socket (Table 1). The adjustable socket moved the patient out of the ABC fall-risk category (his confidence increased from 48.8 percent to 83.1 percent). The PLUS-M measure score increased by 13.8 percent. This score is over twice the minimal detectable change of 5.36 in the PLUS-M, showing a clinically significant functional mobility difference (Figure 1).

Case 2 describes a 44-year-old male with a left transtibial amputation secondary to Buerger's disease. Buerger's is a type of vascular disease that is mainly associated with tobacco use and affects the arteries and veins in the extremities.[3,4] The patient is very active with his children and around his home and was finding it difficult to achieve the correct socket fit throughout the day. His initial socket design was a conventional suction suspension laminated socket with a ProFlex inner socket and a sleeve on the outermost rigid layer. However, his activities resulted in sleeve damage, which eliminated suction within the socket. Lack of suction allowed air into the system, resulting in pistoning. Excessive motion within the socket

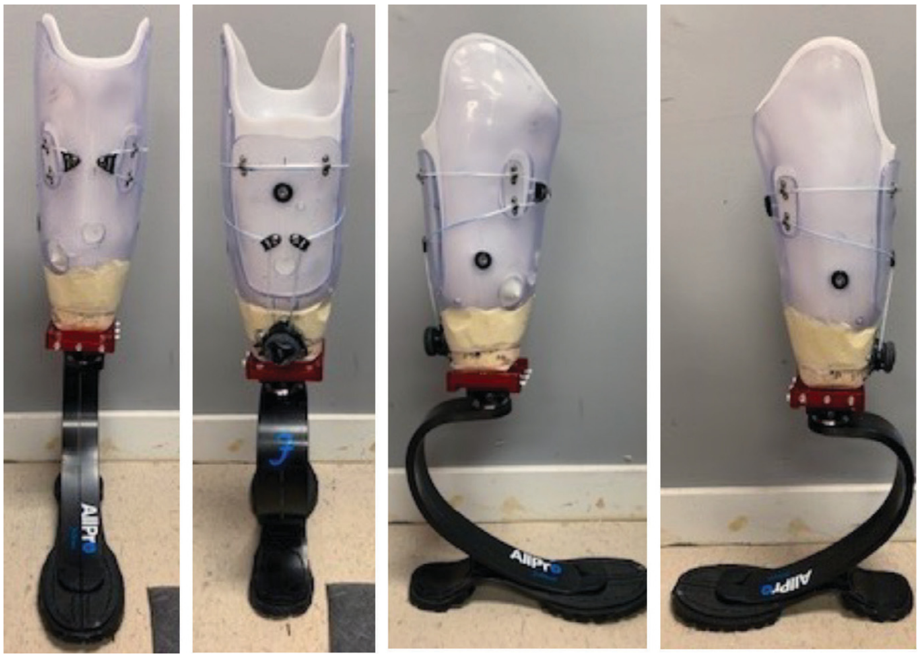


Figure 2. Sagittal and coronal views of a left transtibial socket with adjustable pretibial and posterior panels and hardware attachments screwed into the rigid socket.

Figure 3. Sagittal and coronal views of a left transtibial socket with adjustable pretibial and posterior panels and hardware attachments secured with fiberglass wrap. The suspension sleeve between the flexible and rigid layers is also visible.

Table 2. Case 2 outcome measures comparing the conventional socket to the alternative adjustable socket.

Outcome Measures	Conventional Socket	Adjustable Socket
OPUS HR-QOL	49.68	66.04
ABC	93.1%	NA
PLUS-M	56.3 (76.6%)	64.5 (92.6%)

caused friction and pressure over his anterior distal tibia, resulting in a wound that healed slowly (an effect of Buerger's disease).

A seal-in liner was discussed, but it was found to be inappropriate due to his bony anatomy. A new socket was fabricated to house a sleeve between the rigid and flexible sockets to maintain suction for optimal suspension. A three-panel system was created (two pretibial and one posterior) to address daily residual-limb volume changes and decrease pressure over his anterior distal tibia. This design allowed for suction suspension in the inner flexible socket and adjustability of the rigid exterior socket.

Initially, the adjustable hardware secured the BOA thread tunnels and was attached with screws into the rigid socket (Figure 2). However, the hardware attachments repeatedly disengaged from the socket. For added security with the tunneling system, a fiberglass wrap was added to the socket to secure the adjustable portions during the trial periods (Figure 3). The fiberglass wrap was found to be a more secure method of attaching the BOA tunnels. A sole was stitched to the bottom of the carbon foot, removing the need for a foot shell or shoe. Small holes were drilled into the foot plate, and the soling was stitched onto the foot plate using Kevlar thread.

In the two years since initial fabrication, there have been no failures in the prosthesis. Outcome measures with the conventional socket and the adjustable socket were recorded (Table 2). The main differences in outcome measures were seen in the QOL and functional mobility. The patient scored 7.2 points higher in functional mobility, which is a clinically significant improvement.

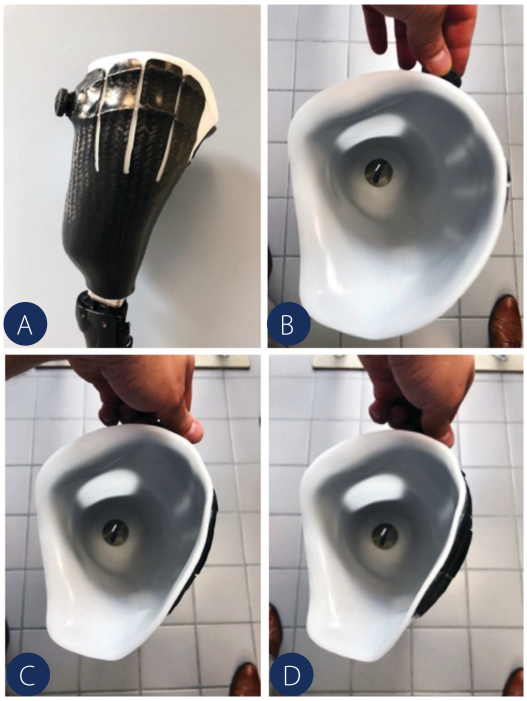


Figure 4. Socket views in the sagittal (A) and transverse planes (B, C, D). Image B shows the socket fully opened. Image C shows the socket halfway tightened. Image D shows the socket fully tightened.

Transfemoral Socket Designs

Case 3 describes a 72-year-old male with a left transfemoral amputation secondary to trauma from a gunshot wound. He was initially fitted with a conventional laminated socket with a ProFlex inner socket and a lanyard suspension system, but soon after the fitting, he began having difficulties donning the prosthesis due to his limb shape, soft-tissue distribution, and hand dexterity.

The lateral wall was made adjustable to help him don the prosthesis with greater ease. Slots were cut into the rigid frame to allow the lateral proximal area to be tightened. Figure 4 shows the difference between the socket with the BOA released, the BOA in mid tension, and the BOA fully tightened. Figure 5 shows an overlay of the socket fully opened and fully tightened to illustrate the amount of shape change. This was one of the first transfemoral socket designs this clinic created using the BOA dial system.

Figure 5. An overlay of images B and D in Figure 4 in the transverse view of the socket fully opened and fully tightened.

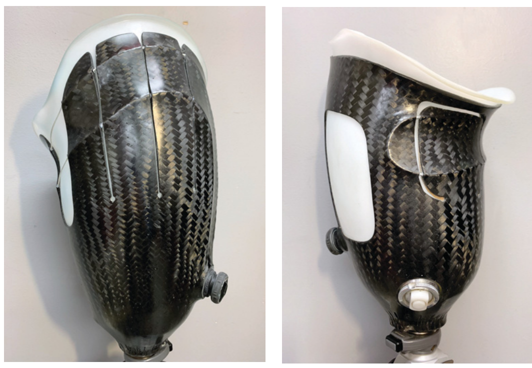


Figure 6. Sagittal and coronal views of the adjustable socket design.

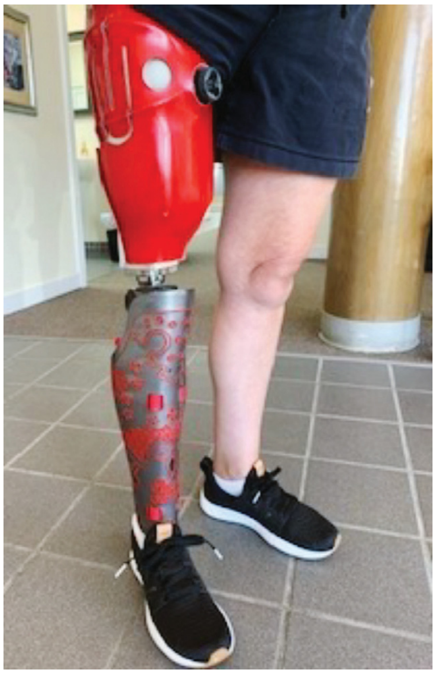
Table 3. Outcome measures comparing the conventional socket and the alternative adjustable socket.

Outcome Measures	Conventional Socket	Adjustable Socket
OPUS HR-QOL	45.2	61.6
ABC	38.1%	83.5%
PLUS-M	34.1 (5.5%)	47.1 (38.5%)

Case 4 describes a 37-year-old female with a right transfemoral amputation secondary to osteosarcoma. She is active at work and at home and began having issues with socket stability as she wore her prosthesis throughout the day. Sock ply adjustment did not fully accommodate her residual-limb volume changes, which created a lack of suction and biomechanical instability within her socket. Her socket was a conventional suction socket with a ProFlex inner socket and laminated outer frame.

An adjustable socket was fabricated to address her concerns. The socket incorporated a ProFlex inner socket, carbon-fiber lamination, and cutouts within the socket that were strung together with a BOA system to create adjustable sections. The socket was adjustable on the proximal mid-to-lateral aspect and subischial triangle to accentuate the three-point pressure system within the socket (Figure 6). This was the second style of adjustable socket trialed for ease of donning and greater biomechanical stability. The patient was able to open the socket for easier donning over her soft tissue and tighten it to create greater biomechanical stability from the subischial triangle, providing more ischial support. Outcome measures were recorded before and after the socket was fabricated. All three scores increased significantly, indicating improvements in QOL, balance confidence, and functional mobility. The ABC score improved enough to pull her out of the fall-risk category (38.1 percent confidence to 83.5 percent confidence). This individual scored 13 points higher in the adjustable socket as compared to the conventional socket, indicating a clinically significant change in her functional mobility.

Case 5 describes a 61-year-old female with a right transfemoral amputation secondary to cancer. This individual has tried several different socket styles designed by different prosthetists. The previous styles included vacuum, lanyard, pin, and suction. Suction suspension was deemed to be the most appropriate for her socket at this time. The patient stated that her greatest concerns were volume fluctuations and instability within the socket. These concerns had not been successfully accommodated in previous socket styles. She complained of very specific painful load-sensitive areas that made previous sock-ply management difficult.



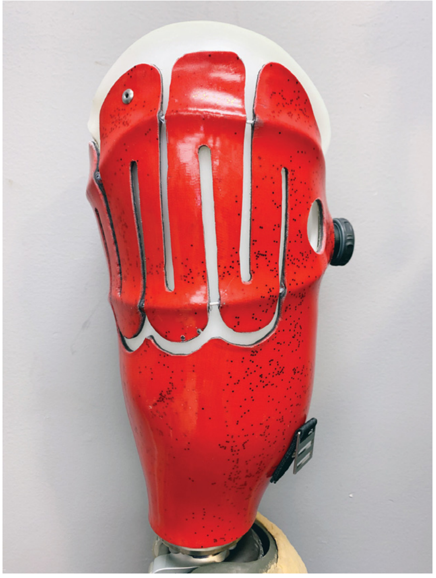


Figure 7. Images of the adjustable socket design. The pattern allows the socket to be tightened along the surface of the socket and in the transverse plane.

A laminated adjustable socket was fabricated over a ProFlex inner socket to address these concerns. Adjustability was added to the proximal and distal portions of the lateral wall. This allowed her to tighten the socket around her suction seal and create more lateral stability while also making it easier to don the prosthesis over her excessive soft tissue. Fabricating slots into the socket created a tightening effect along the surface of the socket and a push in the transverse plane (Figure 7). The lateral push in the transverse plane decreases the volume in the socket, increases suspension within the socket, and increases pressure over the lateral shaft of the femur to reduce pressure over the cut end.

Case 6 describes a 61-year-old male with a left transfemoral amputation secondary to trauma sustained in a motor vehicle accident. This patient is active within his community. He had been using a vacuum socket for most of his daily activities. However, he had begun to lose vacuum and suspension while bicycling.

To increase the security of suspension within the new prosthetic socket during higher level activities, a lanyard system was selected for use during most of his sports-related activities. Lanyard systems had been tried in the past but were unsuccessful due to rotation of his limb within the socket and excessive pressure over his lateral distal femur. These issues were resolved with the design of the new adjustable socket using the lanyard as the main suspension component.

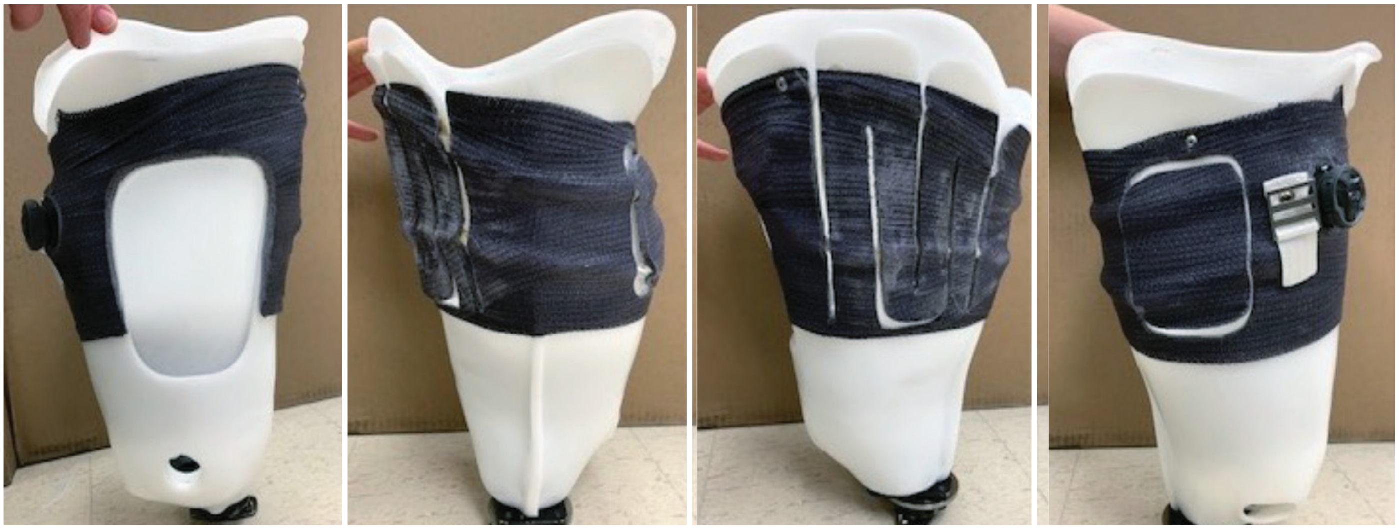


Figure 8. The adjustable socket design with adjustability on the lateral wall and subischial region. The pattern allows the socket to be tightened along the surface of the socket and in the transverse plane.

Features from the previous transfemoral designs were incorporated into his new socket to achieve the greatest biomechanical stability and decrease pressure on the lateral distal femur. For example, an adjustable lateral wall and subischial triangle allowed him to gain more support over the femoral shaft and more ischial support. The design also decreased rotation within the socket by creating a more triangular shape. In the test socket shown in Figure 8, the BOA features were wrapped with fiberglass for security.

Conclusion

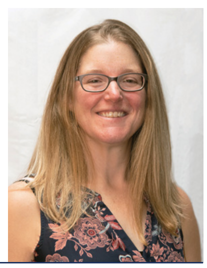
The socket designs described in this article incorporated adjustability to accomplish three goals:

1. To make donning easier
2. To address daily volume fluctuations
3. To take pressure off load-sensitive areas

Outcome measures from several of the patients indicated improved functional mobility, health QOL, and balance confidence.

Anecdotally, all patients said they felt improvement in stability and comfort with the adjustable socket versus the conventional socket. The cases presented in this article show the iterations of each adjustable socket and why specific elements were incorporated into the designs. Creating an alternative-style socket with adjustability allows users to have more control over their prostheses and increases their satisfaction. The main purposes of these designs were to meet patients' specific needs and help them reach their activity and functional goals.

References are available at www.oandp.org/page/ATcurrent.



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