Transradial and Wrist Disarticulation Socket Considerations: Case Studies

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ABSTRACT

There are a myriad of socket designs for the individual with transradial or wrist disarticulation level amputation. Progressive socket designs incorporate anatomic contouring to improve comfort, stability, suspension, range of motion, and, ultimately, function. Advancements in materials science have contributed to the continuing evolution of these designs. The progressive upper extremity practitioner should possess an understanding of the spectrum of socket designs and material characteristics to effectively address an individual's unique physical presentation and occupational goals. Considerations in determining the appropriate socket design include but are not limited to the condition of the residual limb, the control strategy, concomitant issues, and the vocational/avocational goals of the individual. The purpose of this article is to demonstrate how integration of the optimal anatomically contoured socket designs and materials significantly improves rehabilitation outcomes. This will be exemplified through four case studies involving three anatomically contoured socket designs and one elevated vacuum design: 1) a wrist disarticulation level flexible thermoplastic suction socket with micro expulsion valve, 2) a transradial anatomically contoured socket with three quarter modification using flexible thermoplastic, 3) a transradial anatomically contoured socket with three quarter modification using injected silicone and 4) a transradial level socket using elevated vacuum suspension. (*J Prosthet Orthot.* 2008;20:118–125.)

KEY INDEXING TERMS: transradial, wrist disarticulation, socket, anatomically contoured, upper extremity interface

Several innovations in prosthetic socket design have emerged for application at the transradial and wrist disarticulation amputation levels. The introduction of flexible socket materials in contact with the residuum and secured within a rigid framework significantly increases the potential for improved outcomes. It is the belief of the authors that the practitioner of upper extremity prosthetics should possess a thorough understanding of traditional and current socket designs. A grasp of traditional socket designs allows one to identify the particular challenges associated with each of these approaches. Experience with evolving socket designs enables the practitioner to offer solutions to many of these challenges and opportunities to enhance comfort and function. This knowledge is then applied to each unique clinical presentation when choosing the specific socket design and types of materials. Considerations in determining the most appropriate socket design include but are not limited to: the condition of the residual limb, the control strategy, concomitant issues, and an individual's occupational goals.

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Disclosure: The authors declare no conflict of interest.

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Four case studies will be presented to exemplify the advantages of progressive socket designs and materials with respect to comfort, suspension, range of motion, and associated functional gains. The case studies focus on four experienced upper extremity prosthetic users, one at the wrist disarticulation level and three at the transradial level. In all of these cases, the users had not maximized their rehabilitation potential secondary to limitations of their initial socket designs and materials. The rehabilitation team consisted of a physician, prosthetist, occupational therapist, social worker, and prosthetic technician. The team evaluated each user's medical history, physical presentation, personal and family feedback, functional status, and limitations relative to the existing prosthetic system. Based on individual needs, treatment plans including improved socket designs were developed to enhance suspension and stability, enlarge the functional envelope, increase range of motion, and transfer anatomic motion to the prosthesis.

Each case study will provide a brief history with a description of the original prosthetic socket design and its associated benefits and limitations from the user's perspective and the clinical team's evaluation. Details of the treatment progression will follow. The final section of each study discusses the results of the fitting and the overall function of the new prosthetic system based on clinical observations and the user's satisfaction. Although there have been many innovations in socket materials and fitting techniques, we will focus on three anatomically contoured socket designs and one elevated vacuum socket design that were useful in the specific cases presented. These include 1) a wrist disarticulation level flexible thermoplastic suction socket with micro expulsion valve, 2) a transradial level flexible thermoplastic transradial anatomically contoured (TRAC)[1] socket with three quarter modification, 3) a transradial level injected silicone TRAC socket with three quarter modification, and 4) a transradial level socket using elevated vacuum suspension.

CASE STUDY 1

WRIST DISARTICULATION LEVEL

Anatomically contoured flexible thermoplastic suction socket with micro expulsion valve.

SUBJECT INFORMATION

RS is a 70-year-old man with left wrist disarticulation and right middle third transradial amputations secondary to a hay bailer accident at age 59. He is a sole proprietor of a cattle ranch with no employees. His goal was to return to full independence in all of the varied tasks of ranching which include mechanics, planting, irrigating, haying, feeding, rounding up livestock and branding cattle.

PROSTHETIC HISTORY

RS received bilateral myoelectric and bilateral body-powered prostheses at the age of 60. This case study focuses on the socket designs for the left wrist disarticulation level prostheses. The original myoelectric prosthesis incorporated a flexible socket with a windowed laminated frame and removable door. The original body-powered prosthesis was a traditional hard laminated socket with figure 8 harness, triceps cuff, and flexible hinges. At the patient's request, the prosthetic sockets for both original prostheses had been slightly enlarged for ease of independent donning and doffing throughout the work day. During the evaluation, RS stated that both the original left wrist disarticulation level myoelectric and body-powered prostheses "slipped off" his arm and caused soreness on the bony prominences of the styloids after 14+ hour work days. As a bilateral amputee, RS reported difficulty managing the removable door during donning and doffing of the myoelectric prosthesis. Upon examination of the residuum, the clinical team observed irritation over the ulnar styloid. The team also noted the original prostheses migrated distally and restricted pronation, supination, and elbow flexion.

TREATMENT

The team elected to create an anatomically contoured flexible thermoplastic suction socket with micro expulsion valve. An anatomically contoured socket at the wrist disarticulation level focuses soft tissue compression between the radius and ulna. Careful attention is given to the shape of the extensor mass and flexor mass of the proximal forearm to retain socket contact throughout pronation and supination. Traditional approaches, while encouraging a "screwdriver shape" by flattening of the medial and lateral sides of the socket, do not provide stabilizing pressures in the interosseous space. This captures and translates anatomic pronation and supination to the socket a characteristic which has been shown to be a priority for individuals returning maximum function with a prosthesis.[2,3] Critical to the success of this design is the choice of thermoplastic material which allows the socket to expand and recontour around the styloids during donning and doffing. A flexible socket material accommodates the natural movement of the skeletal and musculotendinous structures. By retaining socket orientation with the anatomy throughout the range of motion, pressure points are reduced or eliminated. This assists in maintaining good electrode to skin contact over ideal myo sites in the myoelectric prosthesis. The skeletal suspension and intimate fit of the flexible socket allow for additional suspension through suction maintained by a micro expulsion valve.

RS was fit with a flexible anatomically contoured suction socket with micro expulsion valve and reduced trim-lines for both the new myoelectric and body-powered prostheses. Donning was achieved through the use of an alcohol based lubricant that allowed him to slide the radial and ulnar wrist disarticulations of his residuum past the smaller diameter of the flexible central section of the socket. The team devoted significant effort to contouring the socket to improve rotational stability and capture RS's entire range of motion in pronation and supination. Suspension was enhanced through the suction created by the air tight seal between the individual's residuum and the flexible socket. By suspending the prosthesis in this fashion the pressure points noted in the original prosthesis over the bony prominences of the styloids were eliminated. As a result of the improved suspension, the trim-lines could be reduced without sacrificing socket stability or suspension. (Figure 1) By comparison, the trim-lines of the original design with minimal contouring were necessarily higher to attempt to provide socket stability and suspension. This had the effect of significantly preventing supination and pronation from being translated to the prosthesis. In determining trim-line height it is also important to consider the ideal location of electrodes within the socket.

RESULTS

RS was given a variety of tasks in the clinic occupational therapy department for the purpose of comparing the original and new socket designs. He was able to demonstrate a significant increase in ability to pick up and carry heavy objects and commented repeatedly on the improved comfort. With the new socket design there was no loss of active pronation or supination through the socket. The natural movements were transferred directly to positioning of the terminal device. RS demonstrated freedom to fully flex and extend his elbow secondary to the reduced trim-lines (Figure 2). Additionally, there was improved contact between the skin and electrodes in the myoelectric prosthesis. RS reported that donning was much easier. He was able to use the new prostheses in a variety of tasks in the clinic and later that day at his ranch without tissue irritation over the bony prominences of the styloids. No loss of suspension during pulling and pushing activities with load was noted. RS has continued to use the

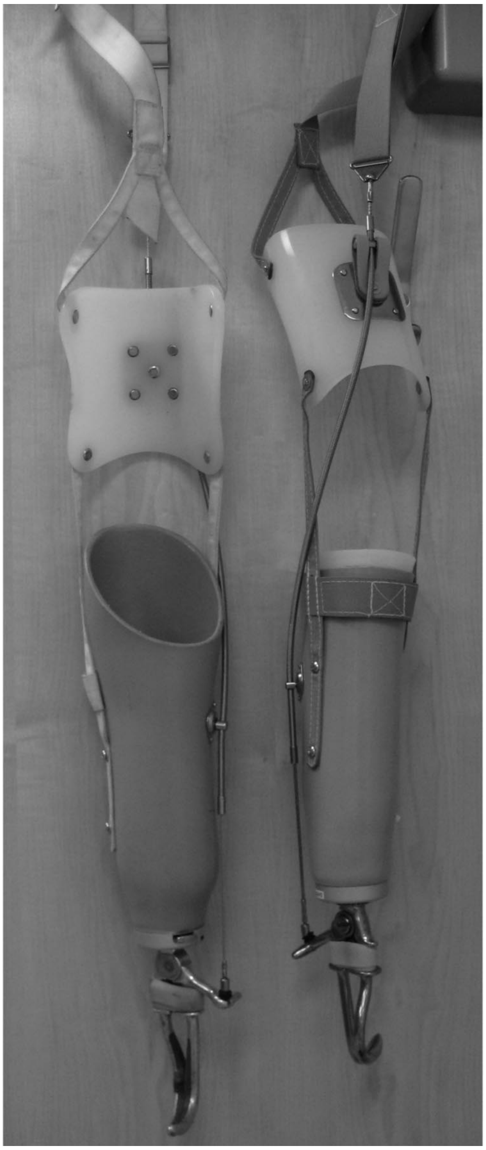

Figure 1. RS: Original rigid sock fit design on left side. Anatomically contoured flexible thermoplastic suction socket with micro expulsion valve on right.

new socket designs in his daily work activities on his cattle ranch.

CASE STUDY 2

TRANSRADIAL LEVEL

A transradial level flexible thermoplastic TRAC socket with three quarter modification.

SUBJECT INFORMATION

MR is a 35-year-old man with a right proximal third transradial amputation secondary to a rock crusher accident. He and his wife have three children ages 1, 3, and 11. His vocation before injury was operating heavy equipment and assembling, operating and maintaining rock crushers. His

Figure 2. RS demonstrating elbow flexion with in new wrist disarticulation level myoelectric prosthesis with anatomically contoured socket. A wrist flexion device further enhances functional envelope.

work involved a high level of physical activity with heavy upper extremity demands. He hoped to return to his previous career with minimal limitations or modifications to equipment and machinery. Another important goal for MR was to return to avocational interests including, hunting, fishing, mechanical work, and other outdoor activities. MR's physical and cognitive abilities for prosthetic control are excellent. His upper extremity range of motion is within functional limits bilaterally. He reports good pain control and tolerates what pain he does have rather than using medication.

PROSTHETIC HISTORY

MR received his original body-powered prosthesis 3 months postinjury. The original prosthesis was constructed with a traditional hard laminated socket with minimal contouring and standard figure 8 harness. MR reported range of motion limitations because of harness constraints and socket design. He did not receive any training with this device and reported frustration with the weak grasp, poor stability on his residuum, and discomfort. Therefore, he used the original body-powered prosthesis primarily as a passive device. He lacked independence or had difficulty with opening containers, manipulating zippers, laces and tools, preparing meals, cutting food, maintaining his yard, and performing childcare tasks. MR was very motivated to be fit with an electric prosthesis to eliminate the restrictive harness and increase his prosthetic control and grip force. He also desired increased comfort and function in a body-powered prosthesis for specific activities. The clinical team observed a limited functional envelope in the original prosthesis during activities that required bilateral reach. Also noted was the lack of socket stability on the residuum and resultant lack of prosthetic control.

TREATMENT

MR and the clinical team analyzed each of the issues presented. To allow this individual to perform his activities of daily living more effectively, the team fit him with a preparatory test socket utilizing the TRAC self suspending socket design for the purposes of creating a preparatory myoelectric prosthesis. This anatomically contoured design focuses on volume containment with aggressive contouring over both soft tissue and skeletal structures to optimize suspension, stability, and range of motion. The use of flexible thermoplastic materials in this design accommodates the natural movement of the skeletal and musculotendinous structures. A rigid laminated framework surrounding this flexible material provides the necessary structure to support the key anatomical areas of the epicondylar and supraolecranon regions[1] and house prosthetic componentry.

After the TRAC test socket was fit, MR immediately noted improvements in the rotational stability, suspension and comfort of the socket. Although range of motion was improved, maximum elbow flexion was still not achieved. He also reported that donning and doffing of the prosthesis was challenging. To improve on these issues, a three quarter modification[4] was created. A three quarter modification is an opening centered over the olecranon and is designed to remove material in the socket and frame which is not required for stability or suspension. The border of a three quarter opening is defined by the apices of the medial and lateral epicondyles, the superior aspect of the olecranon, and the proximal third of the overall length of the residuum from olecranon to distal end. The three quarter modification allowed for an additional increase of elbow flexion by removing any potential constraints or impingement of the olecranon process within the TRAC socket. MR reported decreased effort required during donning and doffing of the prosthesis. This is likely due to the reduced surface area of the socket and frame which decreases the friction of the donning sock between the skin and the socket during donning. The three quarter opening also allowed MR to manipulate the exposed skin during doffing into a more secure position. He commented that ventilation through the socket improved comfort and reduced heat retention. Additionally, the opening provided proprioceptive feedback to the elbow when leaning on counters or interacting with the environment. These findings were applied to create a preparatory myoelectric prosthetic device with functional components.

Figure 3. MR demonstrating trial use of preparatory prosthesis with TRAC flexible thermoplastic socket on four-wheeler.

Figure 4. MR demonstrating definitive prosthesis with TRAC flexible thermoplastic socket on heavy equipment.

RESULTS

MR demonstrated excellent control of the preparatory myoelectric prosthesis with TRAC three quarter modified socket with a notable increase in comfort, function, and range of motion. During occupational therapy, he practiced carrying objects from one area to another, incorporating the prosthesis appropriately. MR also lifted items to place them on a shelf, demonstrating increased range of motion. He drove a "four-wheeler" vehicle without loss of grasp and with comfort in the anatomically contoured socket (Figure 3). On the day of the fitting, he reported comfort in the socket during loading activities that included shoveling, raking, reeling when fishing, and emptying garbage cans.

After definitive fabrication, MR was accompanied to a heavy equipment operating site and further occupational therapy was performed (Figure 4). The subject demonstrated appropriate grip patterns to safely mount, operate, and dismount a variety of heavy equipment. He noted a vast improvement in function during these exercises. He returned to full time work within 5 days of definitive fabrication. Based on MR's experience with the anatomically contoured socket for the myoelectric prosthesis, he requested that his new body-powered prosthesis be fabricated with the same socket design. When this fitting took place, the suspension of the anatomically contoured socket eliminated the need for a restrictive figure 8 harness that MR had disliked in his original prosthesis. A figure 9 harness was adequate to control cable-operated functions. At this time, the subject integrates both prostheses throughout his 12 to 15 hour work days depending on the specific task to be accomplished.

CASE STUDY 3

TRANSRADIAL LEVEL

A transradial level injected silicone TRAC socket with three quarter modification.

SUBJECT INFORMATION

LG is a 62-year-old man with a right transradial amputation secondary to a farming accident at the age of 16. His residual limb has extensive adherent scar tissue on the distal end and exaggerated bony prominences which create a persistent challenge for comfortable prosthetic fit. He was originally fit with a body-powered prosthesis. Throughout his adult life he has pursued a career in bookkeeping and accounting. His avocational interests included gardening and home maintenance projects. At the age of 55, LG developed severe overuse and axillary impingement on the contralateral side secondary to long-term use of the original prosthesis. LG expressed a desire to move away from a harnessed prosthesis and reduce his painful symptoms. He was very interested in achieving a high level of bimanual function by incorporating an electric prosthesis into all activities of daily life. LG also expressed a desire for a nonelectric prosthesis to use in gardening and home maintenance tasks.

PROSTHETIC HISTORY

Soon after the initial injury, LG was fit with a body-powered prosthesis with figure 8 harness. He used this style of prosthesis until approximately age 55 at which point his symptoms became severe. LG's desire to be fit with a prosthesis that does not utilize a harness is common amongst upper extremity prosthesis users.[5] At that time, he was fit with a myoelectric prosthesis utilizing a socket design approximating a Muenster style[6,7] self-suspending design to eliminate the harness of the body-powered device. LG found moderate function with this device but experienced a lack of suspension, range of motion, comfort and stability. These issues prevented him from integrating the prosthesis into the full scope of his activities of daily living. He continued to rely on his sound limb for most tasks which exacerbated to his contralateral shoulder pain and overuse. The clinical team observed the issues reported by LG while using his myoelectric prosthesis in the clinic.

TREATMENT

The limitations of the original self-suspending myoelectric socket were identified as inadequate suspension, comfort, and stability. The clinical team addressed these issues by fitting a new transradial myoelectric prosthesis utilizing a TRAC self suspending socket with a three quarter modification to the elbow region. This first preparatory prosthesis with a flexible thermoplastic anatomically contoured socket was well received by LG. He found that the new socket improved suspension and stability, decreased heat retention, provided better electrode contact with the skin, and enlarged the functional envelope.

During a 2 week trial wearing his preparatory prosthesis, the new socket design allowed LG to use his prosthesis more proficiently in all of his daily activities. However, the increase in prosthetic use led to painful irritation of the adherent scar tissue on the distal aspect of the residuum. LG's many bony prominences were still difficult to accommodate throughout the entire range of motion, and he experienced discomfort in extreme positioning of the prosthesis. This was particularly noticeable when he attempted to pick up heavy objects. The clinical team noted a positive increase in flexion and extension of the elbow over the previous design, and also identified a potential for further improvement. The remaining limitations could be attributed to the firmness of the flexible thermoplastic material of the socket. It was decided to transition from the flexible thermoplastic material to silicone while maintaining the principles of the TRAC design.

A new socket was designed using a soft 10 shore (durometer) injection molded silicone to create a custom TRAC liner. The silicone liner was contained within a typical TRAC three-quarter modified rigid laminated frame for a trial fitting. Immediate benefits were realized as LG's discomfort over the distal adherent scar resolved. The silicone better protected the prominent bony anatomy and further increased the range of motion by approximately twenty degrees in flexion and 10 degrees in extension over the thermoplastic socket. This was likely due to the increased flexibility of the proximal posterior trim-line (Figure 5). Unfortunately, the 10 shore silicone socket was excessively flexible which allowed significant electrode migration and was not strong enough to maintain a secure attachment to the laminated frame. A second liner was injected using 40 shore silicone. It was predicted that LG would see a reduction in the overall range of motion secondary to the firmer silicone material. Surprisingly, he experienced a further improvement in range of motion with the added benefits of secure electrode placement and a more secure attachment to the outer rigid frame. The excessive flexibility of the 10 shore silicone had permitted motion between the socket and the frame. Although there was an increase in flexion and extension over the thermoplastic socket, there was a loss of transferred motion. The use of 40 shore silicone in the socket increased both transferred motion to the prosthesis and overall elbow range of motion. The properties of the silicone material allowed anatomical contouring to be even more aggressive than was possible with the flexible thermoplastic material which then translated movements of the residuum through the socket and the prosthesis with minimal loss.

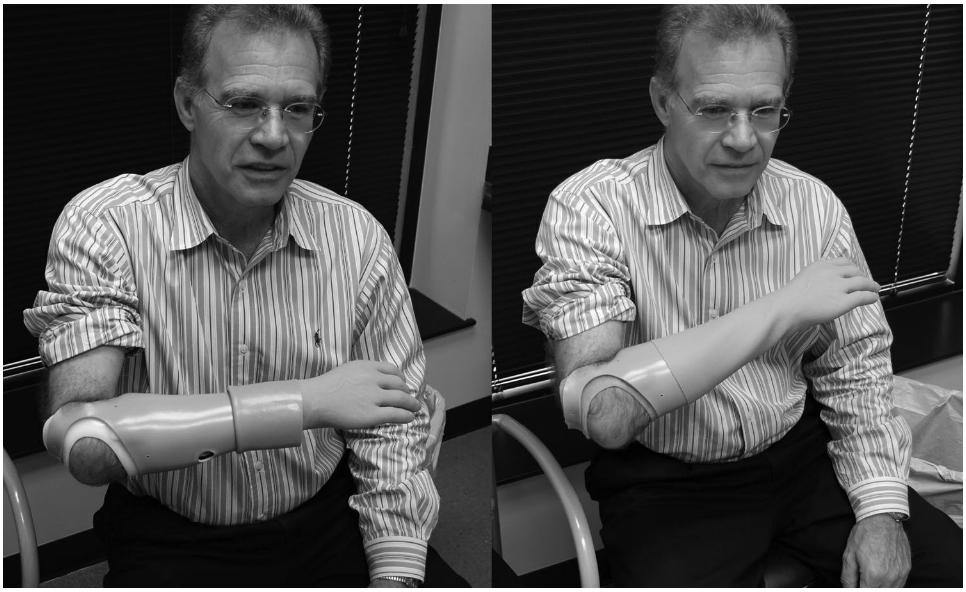

Figure 5. LG demonstrating TRAC flexible thermoplastic socket on the left. At right, LG demonstrating TRAC injected silicone socket with resulting increased range of motion.

RESULTS

LG was observed performing a variety of simulated tasks in the clinic that demonstrated significant improvement in suspension, range of motion, and function. At this time, he is using a definitive prosthesis with an injection molded 40 shore silicone socket and is extremely active. He routinely wears this prosthesis for 16+ hours per day, reporting a consistent level of satisfaction with his functional ability and comfort. Secondary to these improvements, a silicone socket was created for a task specific gardening and home maintenance prosthesis that LG also uses on a regular basis.

CASE STUDY 4

TRANSRADIAL LEVEL

A transradial level socket using elevated vacuum suspension.

SUBJECT INFORMATION

BD is a 25-year-old man with a short transradial level amputation secondary to a blast injury in 2004. During his initial rehabilitation, he was fit in a myoelectric prosthesis using a TRAC socket design and a body-powered prosthesis with roll-on liner and pin-lock suspension. BD became a rock climbing enthusiast after his amputation. He desired to integrate a task specific prosthesis into his life to pursue this interest.

PROSTHETIC HISTORY

BD's primary prosthesis is a myoelectric device using a TRAC socket with three quarter modification. He reports consistent use of his primary prosthesis every day and has fully integrated it into all activities of daily life. BD also has a body-powered prosthesis which he uses on occasion. After developing an interest in rock climbing, he was initially fit with a self-suspended activity specific prosthesis using a TRAC socket and frame design similar to that of his myoelectric prosthesis (Figure 6). The alignment of the terminal device, or ice axe in this case, was determined by the positions required for climbing rather that the positions used for typical terminal devices and activities. The original anatomically contoured design suspended reasonably well and allowed him to improve his skills as a rock climber. However, as BD began to increase the length and difficulty of his climbs, the extreme pressures of holding his weight with the prosthesis began to cause skin trauma to the residuum. Excessive point pressures over the olecranon and epicondyles developed secondary to distraction when BD pulled some or all of his body weight upwards.

BD expressed a desire to improve on the suspension of his rock climbing prosthesis and to reduce these point pressures

Figure 6. BD wearing activity specific prosthesis with a TRAC socket and frame design similar to that of his myoelectric prosthesis.

to allow for longer and more strenuous climbs. He was then fit with a prosthesis using a roll-on silicone suspension liner with pin lock mechanism for suspension similar to his existing body-powered prosthesis. This suspension technique decreased pressure over the bony prominences but created a new problem of tissue distraction from negative pressure at the distal end of the suspension liner. This negative pressure resulted in bruising to the distal aspect of BD's residuum. The clinical team identified the areas of concern with visual inspections of the skin and observation of BD utilizing both of these designs on a climbing wall.

TREATMENT

The clinical team's solution was an elevated vacuum socket design to maintain stability of the prosthesis on the residuum. Elevated vacuum socket designs have been discussed in a number of articles regarding lower extremity prosthetic applications.[8,9] Lower extremity prosthetic use generally creates primary compression forces and secondary distraction forces while the converse is more typical in upper extremity prosthetic use. However, the principles of evaluated vacuum for suspension remains constant in both applications. In an upper extremity socket design, the general principles of anatomical contouring that optimize stability and suspension are replaced with elevated vacuum suspension. To create an air tight seal, a prosthetic socket was fabricated with the combination of an intimately fitted inner silicone liner on the residuum, inserted into a rigid socket housed within a laminated frame and sealed with an outer sealing sleeve. A one way valve is installed in the socket and exits through the laminated frame. Vacuum, or negative pressure, is introduced by the use of a small hand held vacuum pump. The vacuum created is isolated between the socket of the prosthesis and the liner worn over the individual's residuum, thus protecting the residuum from the point pressures, bruising and tissue distraction experienced in the previous socket designs. The elements of this design create enough negative pressure to withstand distraction forces when compared with other socket designs that were tried.

RESULTS

BD found rock climbing challenging to perform comfortably with the first two task specific prostheses. He and the clinical team were able to identify specific areas of discomfort in suspension. With the elevated vacuum socket, BD reported no discomfort in the residuum regardless of the amount of body weight lifted with the prosthesis (Figure 7). The pressure distribution of elevated vacuum suspension, in lieu of the aggressive anatomically contoured suspensory elements of the TRAC design, provided the user with confidence and comfort under the extreme conditions of rock climbing. BD reported continuous comfort and lack of trauma to the residuum during periods of use exceeding 2 hours.

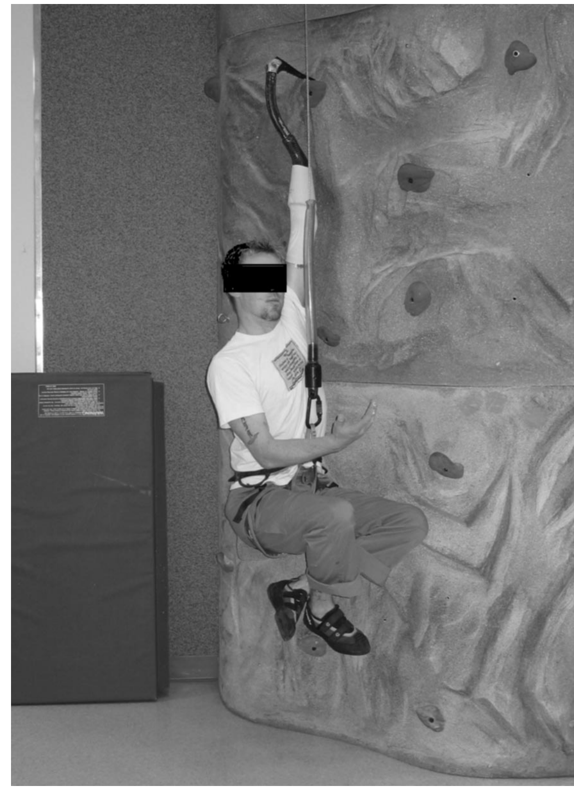

Figure 7. BD demonstrating the ability to suspend his entire body weight from the prosthesis with negative pressure socket. Note the safety harness seen here only functions to reduce fall speed and does not provide upward pull.

CONCLUSION

The four case studies discussed have highlighted the critical importance of socket design. The wrist disarticulation level and three transradial level subjects presented with specific concerns regarding the suspension, comfort, and range of motion of their original prostheses. After the rehabilitation team reviewed their prosthetic systems and limitations, new socket designs and materials were applied to address the issues. The subjects offered specific feedback at the time of the updated socket fitting and at follow-up after they had some experience in their home, work, and recreational environments. Marked improvements while performing activities of daily living and vocational and avocational pursuits were reported by the subjects and observed by the team. Anatomically contoured socket designs which focus on careful soft tissue management and integration of skeletal structures have been shown to significantly improve suspension, stability, range of motion, and comfort. In the authors' experience, elevated vacuum suspension has also been effective for some cases. Choosing the appropriate socket design and materials has a direct, positive effect on overall user function and satisfaction.

Each of these case studies required variations in design and materials to address the needs of the subjects relative to their presentation and occupational goals. The dynamics of anatomically contoured socket designs, an elevated vacuum design and some current materials were explored. Although these case studies demonstrate enhancements made for existing prosthetic users, it should be noted that for individuals being fit for the first time, additional criteria may be considered. Examples of important criteria not studied in depth in this article would include prosthetic control strategies, volumetric changes, and concomitant injuries. The progressive upper extremity practitioner should possess a comprehensive understanding of the spectrum of socket designs and material characteristics in order to optimize prosthetic suspension, comfort and range of motion.

ACKNOWLEDGMENTS

The authors are grateful to Michelle D. Miguelez for her contributions to this article.

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