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The MicroFrame: The Next Generation of Interface Design for Glenohumeral Disarticulation and Associated Levels of Limb Deficiency

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ABSTRACT

The provision of a prosthesis for upper extremity amputees at the glenohumeral disarticulation and associated levels (humeral neck, interscapulothoracic) requires consideration of myriad factors, some of which may include componentry, interface design, fabrication, practitioner experience, and therapeutic intervention. Although state-of-the-art componentry, for example, can dramatically improve outcomes, other factors left unaddressed can negate any advantages that new technology offers. Specifically, the interface is the foundation for successful prosthetic intervention because it can either create conditions that make wearing the prosthesis intolerable or allow high level amputees who were previously not considered candidates finally to benefit from prosthetic intervention. Many individuals fit with a prosthesis at the humeral neck level and higher often complain about the weight of the prosthesis, heat build-up while wearing the prosthesis, lack of stability, difficulty in independent donning, and reduced control of the terminal device when it is positioned in certain planes and body positions; the prostheses have resulted in reduced wearing times and, in many cases, discontinuation of prosthetic use altogether. Although a panacea does not exist, the MicroFrame design addresses these issues more effectively than the traditional interface designs taught in schools today. The purpose of this article is to detail the clinical application of the MicroFrame design. (This MicroFrame may not be appropriate for individuals without delto-pectoral definition and growing children because the anterior/posterior compression of the interface is precisely contoured to the anatomy and must remain constant.)

Amputees or individuals with congenital deficiencies at the glenohumeral disarticulation and associated levels (humeral neck, interscapulothoracic) have historically demonstrated lower prosthetic use patterns than those in whom more of the residual limb remains (transhumeral, transradial, etc.). Individuals with higher level deficiencies most frequently attribute their diminished or discontinued use of a prosthesis to the excessive weight of the prosthesis, heat build-up while wearing the prosthesis, lack of stability, difficulty in independent donning, and reduced control of the terminal device while in certain planes and body positions. These issues are directly related to the design of the interface. An interface must provide a comfortable and stable platform to which components are affixed. If a patient is unable to tolerate wearing the prosthesis, the functional benefits of that prosthesis, regardless of the sophistication of the componentry, cannot be realized.

The three interface designs most common in today's prosthetic practice ("encapsulated," "modified encapsulated," and Sauter Frame) for glenohumeral disarticulation and associated levels do not adequately address the issues of comfort and stability because of their encapsulation of the shoulder complex. Because the shoulder complex changes shape throughout its range of motion, encapsulation results in a loss of stability secondary to a loss in total contact between the interface and the body as the patient ranges the shoulder. Additionally, the changes in shape of the shoulder complex result in localized pressure on the acromial region, a prominent skeletal protuberance that lacks sufficient tissue padding to support the weight of the prosthesis. This is easily verified by examination of individuals fit with these designs because they often exhibit tissue irritation and/or ulceration about the acromial region. The encapsulated and modified encapsulated designs also prevent heat dissipation by limiting air circulation around the enclosed shoulder complex tissues, especially the remnants of the axillary tissue. This results in unacceptable heat build-up for the wearer. The encapsulated design (Figure 1) covers the largest amount of surface area, including a significant aspect of the torso, resulting in greater heat build-up and an increase of overall weight. While the modified encapsulated design (Figure 2) reduces skin coverage and weight, it does so at the cost of stability, often necessitating a more restrictive harness system. The modified encapsulated design lacks adequate terminal device control secondary to interface instability either by loss of electrode to skin contact in a myoelectric control strategy or compromised excursion in a body-powered strategy. The Sauter Frame design (Figure 3) seeks to improve upon the other designs by incorporating windows into the interface and by addressing the issues of heat build-up and overall weight. However, the Sauter Frame, like the previously discussed designs, presents challenges to stability and comfort because the shoulder complex remains encapsulated and excessive pressure continues to be applied to the acromion.

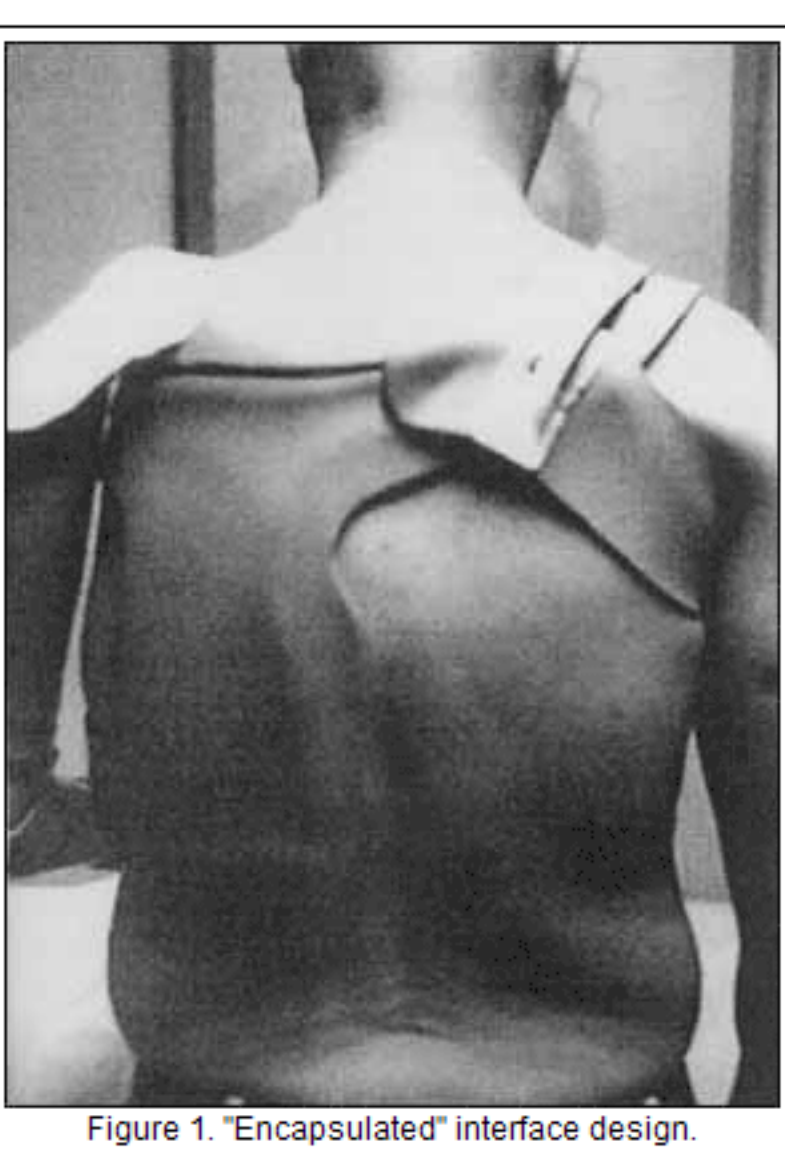
Figure 1. "Encapsulated" interface design.

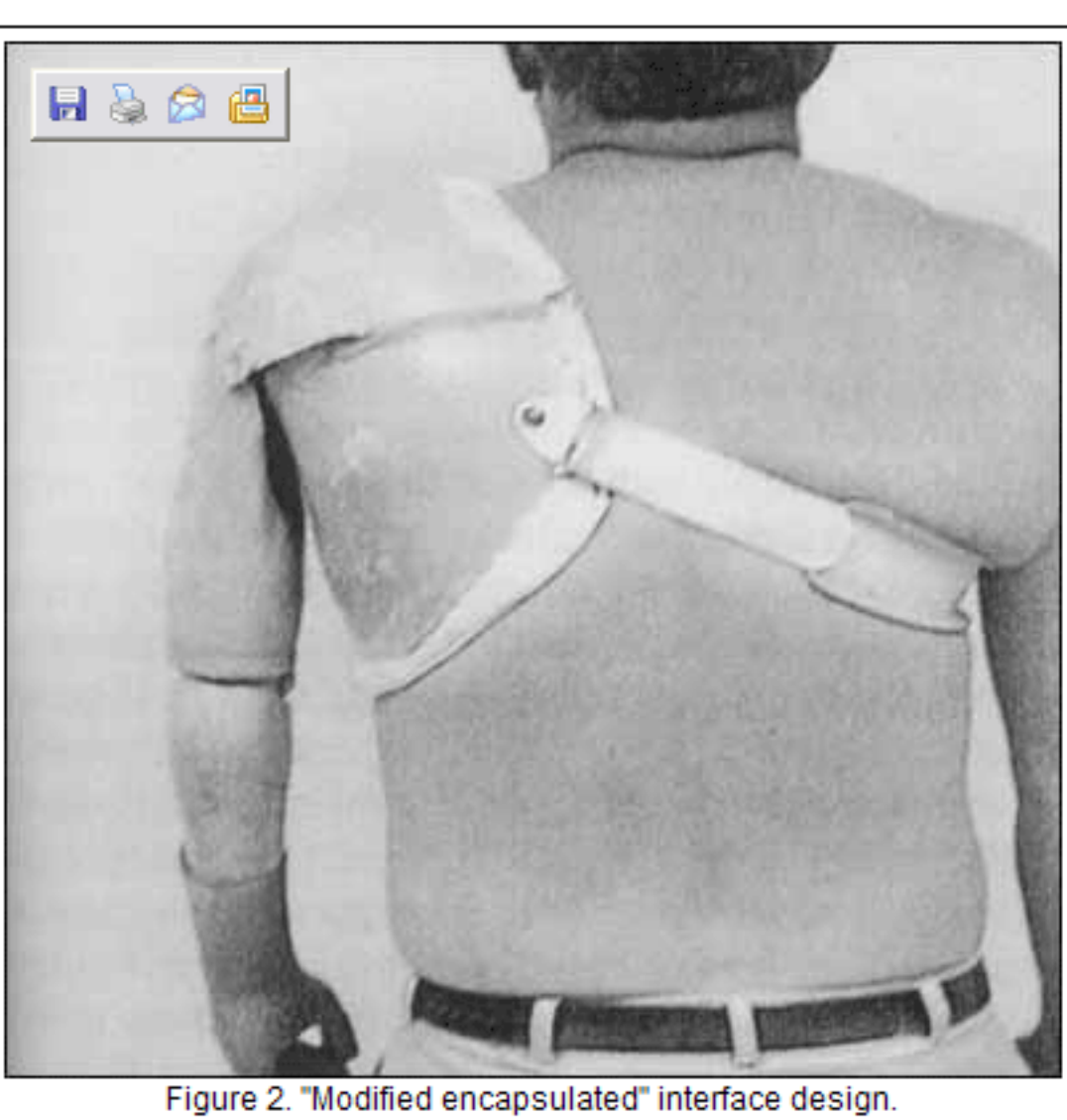
Figure 2. "Modified encapsulated" interface design.

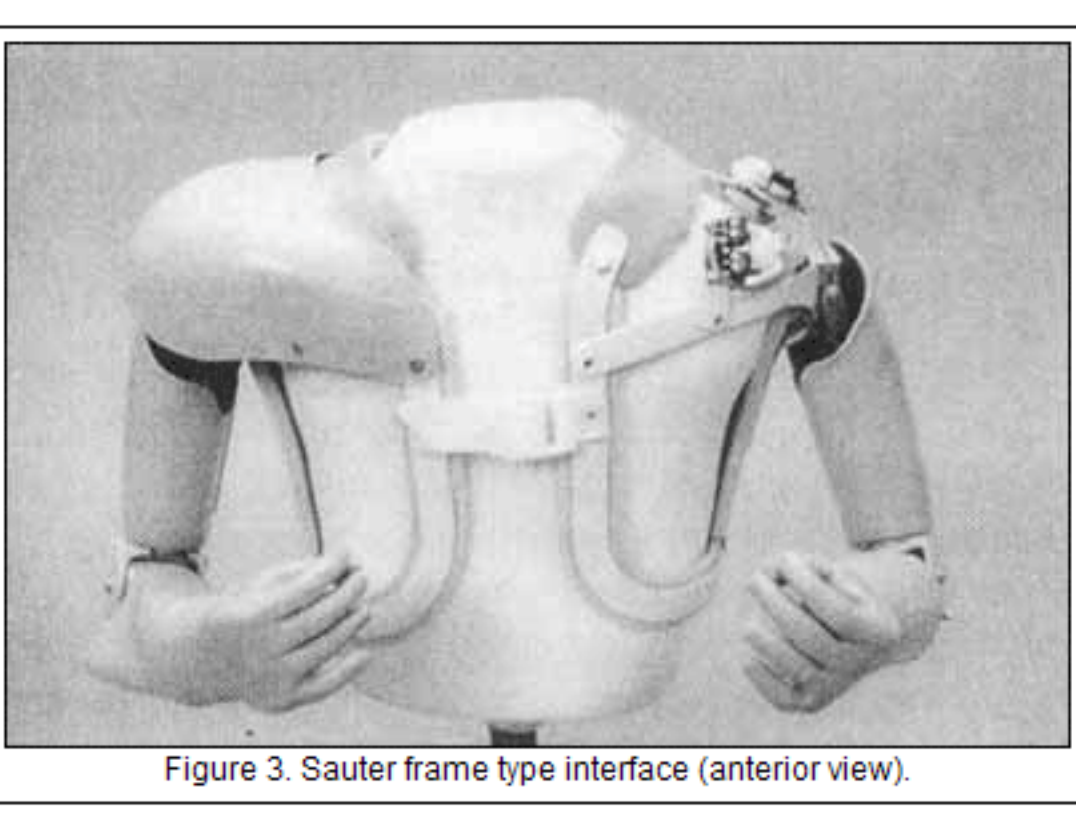
Figure 3. Sauter frame type interface (anterior view).

The MicroFrame interface was created in response to the limitations of the three most common interface designs used in contemporary clinical practice. The objective was to create an interface that reduced skin coverage, enhanced stability, decreased heat build-up and overall and perceived weight, improved terminal device control, and facilitated donning. The central innovation was to liberate the shoulder complex and redistribute the forces of the prosthesis on more tolerant anatomy. By eliminating the shoulder complex from the interface, range of motion and associated anatomical changes in its shape no longer adversely impacted stability, comfort, and control. Because the shoulder complex is no longer required for suspension, it can now be used to activate secondary control inputs.

Stability in the frame design is achieved in the coronal, sagittal, and transverse planes through soft tissue compression and further anatomical contouring, creating a musculoskeletal "lock" comprised of anterior, posterior, and medial force vectors. This ensures superior vertical loading capabilities (improved suspension and tolerance) and enhanced rotational control. Specifically, this control is achieved by compression anteriorly of the proximal aspect of the pectoralis major, posteriorly of the infraspinatus and over the scapular spine, and medially of the latissimus dorsi, serratus anterior, and external oblique muscles, and finally, uniformly applied to the skeletal substructure.[1] This MicroFrame may not be appropriate for individuals without delto-pectoral definition and growing children because the anterior/posterior compression of the interface is precisely contoured to the anatomy and must remain constant.

Methods

Microframe Impression Technique

The first step in the impression technique is to determine the trim lines of the interface. This can be done only by referring to the desired prosthetic control scheme (cable-operated, myoelectric, passive, etc.). The superior trim lines of an interface for a cable-operated or passive prosthesis can be reduced because the interface provides support and stabilization only for these types of prostheses (Figure 4). Extending the trim lines of an interface for a cable-operated prosthesis does not capture any greater gross body movements or produce increased excursion and, therefore, is not advantageous. A passive prosthesis is often lighter in weight than other prosthetic options; thus, a reduction of surface loading areas is acceptable. For the interface of a myoelectric prosthesis, the prosthetist must begin with a myotest to identify optimal EMG site locations that dictate the medial superior trim lines. This can result in trim lines that extend further toward the midline than is necessary for stability and load dispersal but are crucial for optimal EMG signal recognition. Muscles that are often utilized for myoelectric control include the pectoralis, anterior and posterior deltoid groups, infraspinatus, supraspinatus, and teres minor. (Note: The procedure outlined here has been submitted for publication to the *Atlas of Limb Prosthetics.*)

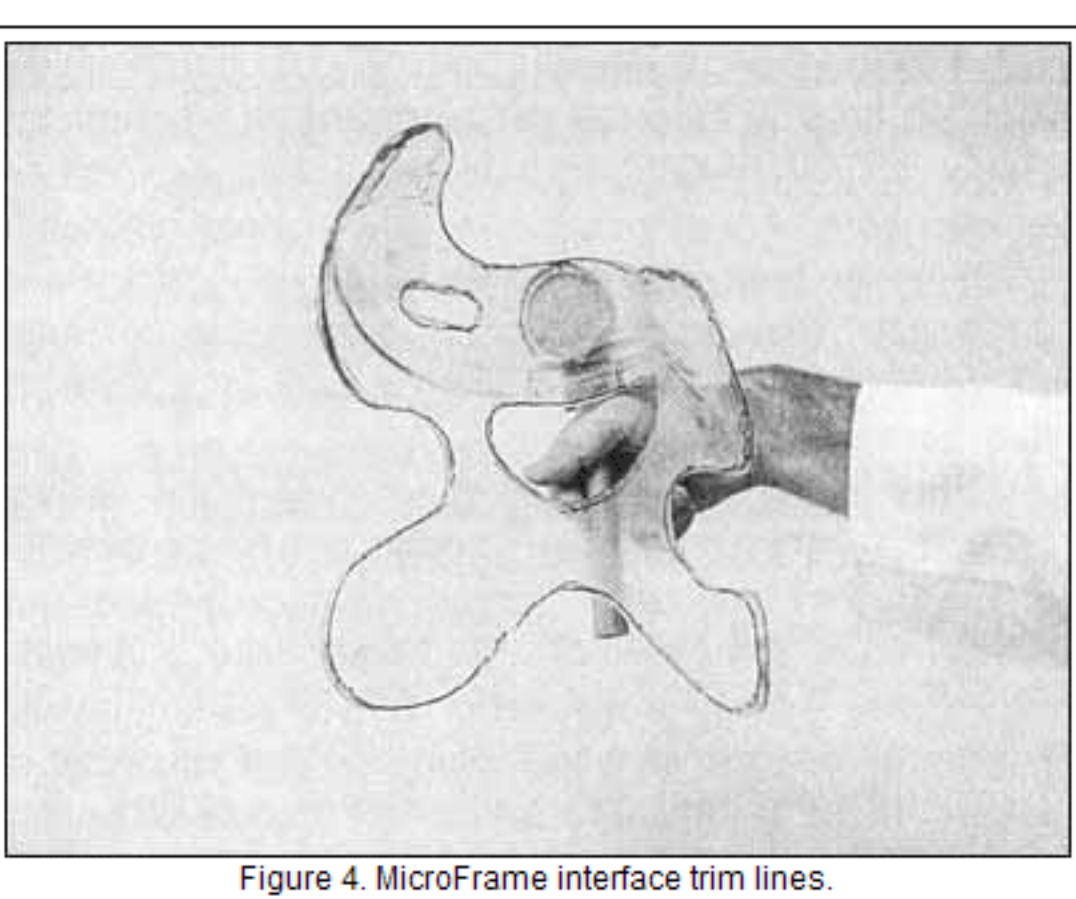
Figure 4. MicroFrame interface trim lines.

In general, the trim lines of the anterior superior stabilizer of the MicroFrame are established through a compression of the delto-pectoral groove and pectoralis muscle group ending below the coracoid process and acromion, and medially, approximately 2 to 3 inches from midline. The posterior superior stabilizer extends across the spine of the scapula below the coracoid process and acromion and medially approximately 2 to 4 inches from midline. The inferior trim lines resemble an inverted Y- shape with minimal interface material extending inferior to the superior stabilizers at the nipple level and then extending toward midline both anteriorly and posteriorly, ending 3 to 4 inches from sagittal midline at the level of the inferior costal margin. The anterior inferior stabilizer curves superiorly at its medial border to facilitate torso bending, especially critical for comfort while seated.

Once the trim lines are determined, they can be marked on the patient for reference with an indelible pen. The shoulder center or location of the prosthetic shoulder unit should also be marked to match the contralateral shoulder center and angle, taking care to determine the desired abduction/adduction and internal/external rotation. Should myoelectric control be desired, EMG sites should also be marked. Bone spurs and scar- and graft tissue should also be marked and palpated to determine load-bearing tolerance. It is also helpful to mark a line perpendicular to the ground through the shoulder center on the lateral aspect to orient the cast during modification. This line can be especially useful for patients with poor posture.

Prepare rigid fast-setting plaster splints at least 6 inches, wide with no fewer than 10 layers, and extending approximately 1 to 2 inches past trim lines along the horizontal plane from the anterior trim lines to the posterior trim lines marked on the patient. (Note: extra-fast-setting plaster splints produce excessive heat during curing and can burn a patient.) Prepare three rolls of 4- or 6-inch elastic plaster bandage and two to three rolls of 6 inch Ace bandages. Wrap cellophane around the patient's torso and shoulder complex and trace all markings with indelible pen on cellophane. The use of cellophane allows for a cleaner casting procedure, eliminates the possibility of the patient's hair being trapped in the casting material, and allows for easy transfer of markings to the negative impression (Figure 5). However, care should be taken to minimize the duration that the cellophane is applied because heat build-up can be uncomfortable. For this reason, staging of plaster splints and ace wrap should occur before application of cellophane.

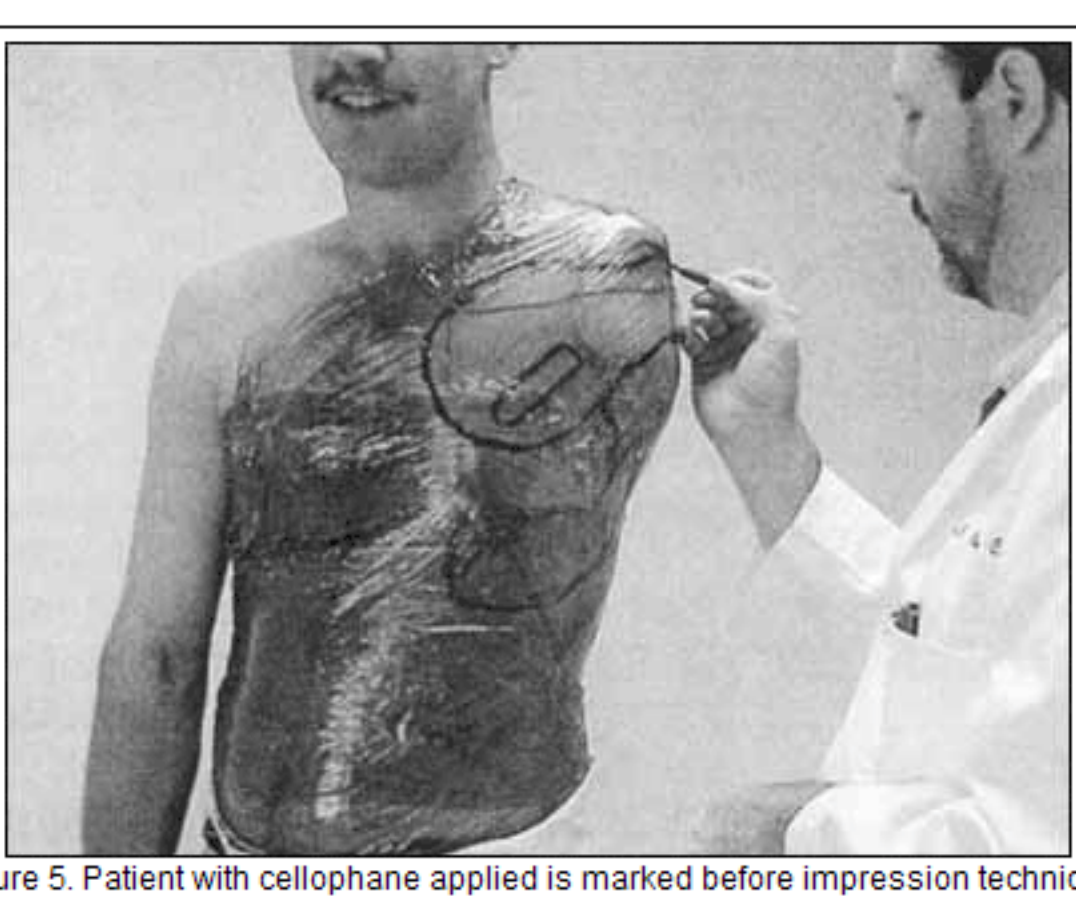
Figure 5. Patient with cellophane applied is marked before impression technique.

Apply the rigid plaster splints horizontally, overlapping the trim lines at least 1 to 2 inches, until all trim lines are covered. Next, apply with tension the elastic plaster circumferentially around the patient's torso encapsulating the shoulder complex of the affected side. Then apply the Ace bandage circumferentially around the patient's torso encapsulating the shoulder complex of the affected side. Using your hypothenar eminence (the ball of the hand), compress in the region of the delto-pectoral groove, pressing down toward the midline of the patient at a 45 degree angle and apply equal opposing force with your other hand across the spine of the scapula again pressing down toward the midline of the patient at a 45 degree angle (Figure 6). This technique provides a precise contour of the load-bearing surface. When performed correctly, the cast should create a wedge-like effect on the patient, settling on the pectoralis muscle group anteriorly and scapular region posteriorly. Because of the number of plaster splints, elastic circumferential wrap, and application of the Ace wrap, the working time is minimal and this procedure requires an expeditious approach facilitated by an assistant. Once the plaster impression has cured, remove the Ace bandage and carefully cut the plaster and cellophane with bandage scissors along the anterior and posterior midline. Remove the negative plaster impression using caution not to spread the anterior/posterior (A/P) aspect because this will result in an ill-fitting interface (Figure 7). Reinforce the negative plaster impression superiorly and inferiorly, trace any markings, and place impression in a supportive medium such as sand, again to ensure that the A/P dimensions do not distort. A pipe should be inserted from the inferior aspect of the impression to facilitate model rectification. Fill negative impression with a mix of plaster and vermiculite.

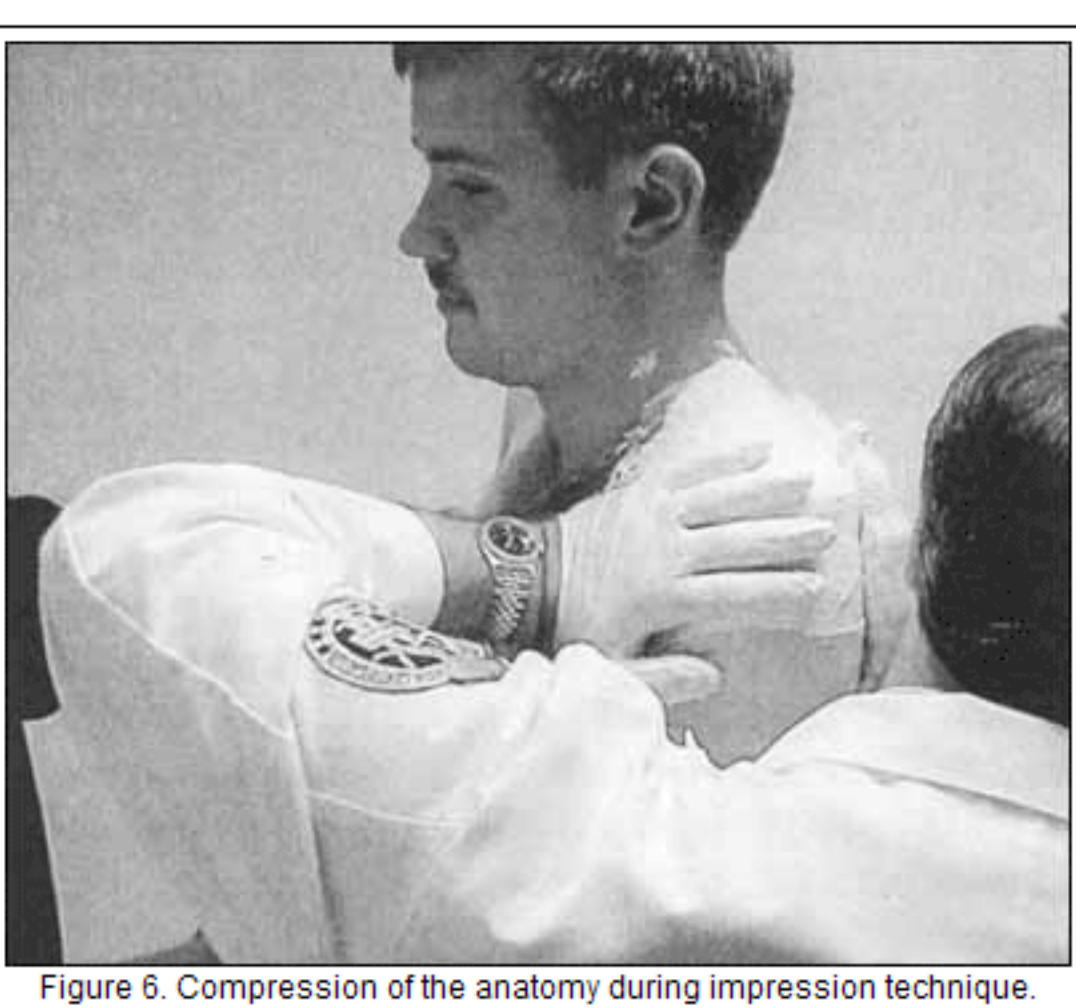
Figure 6. Compression of the anatomy during impression technique.

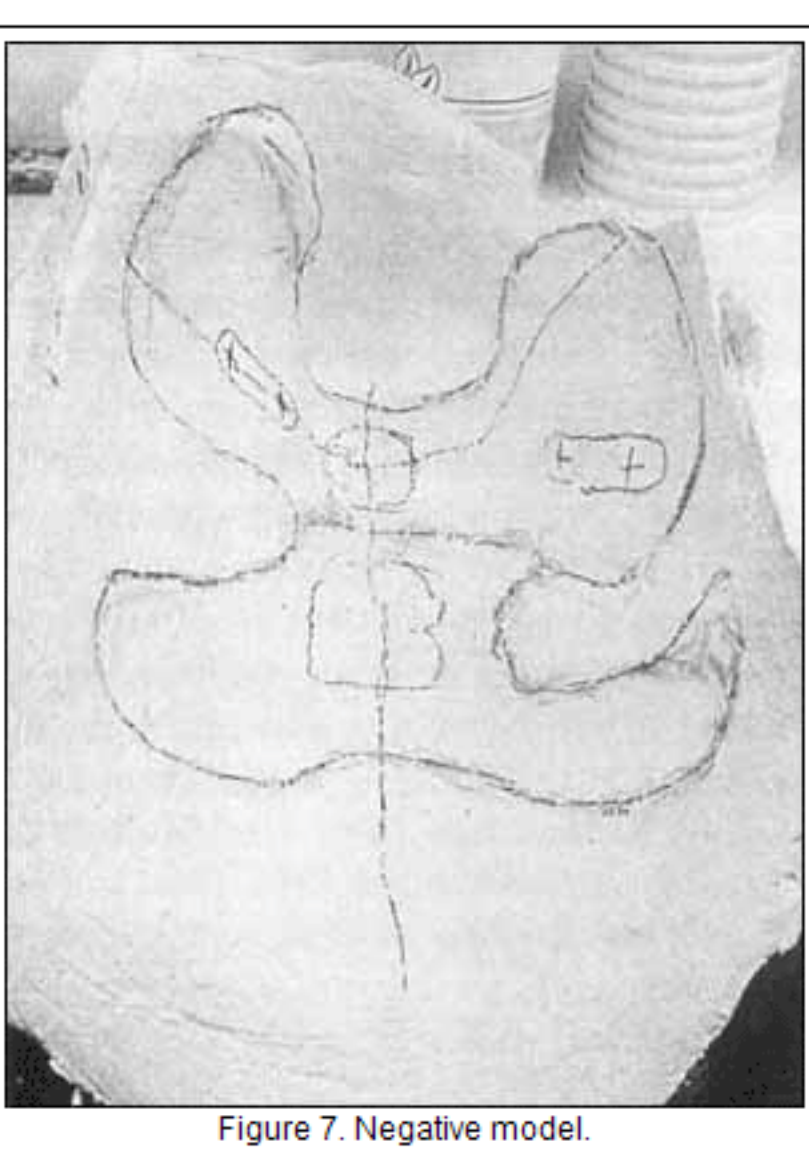
Figure 7. Negative model.

Model Rectification

Once the plaster/vermiculite positive model is cured, remove plaster splints and trace trim lines, shoulder joint center, and electromyographic (EMG) site locations. Model rectification is extremely basic when proper compression in the A/P plane occurs during impression technique. Smooth the overall model and remove approximately 1/4 to 3/8 inches of plaster from the center of the inferior stabilizer extending from the anterior to the posterior aspect to create a concavity or flare at the inferior aspect of the model. This shape improves comfort and range of motion during lateral and anterior trunk bending and during seating. Please note, this concavity and resulting inferior flare away from the body is of particular importance for individuals with pronounced abdomens. Place the shoulder joint dummy as marked on the model being careful to retain appropriate abduction/adduction and internal rotation. Create a diagnostic interface using inch clear thermoplastic to ensure rigidity in the A/P plane. Attach elastic harness material approximately 2 to 3 inches in width to the anterior superior and inferior stabilizers, crossing on the contralateral aspect of the torso, approximately at the nipple line, staying well below the contralateral axilla. The strap extends between the superior stabilizer and the opposing inferior stabilizer. This elastic harness seats the diagnostic interface securely on the body, enhancing load-bearing capabilities and maintaining skin-to-electrode contact. The harness straps should be permanently attached at the cross point for ease of donning and doffing. Often the definitive harness is cut from one large piece of material.

Diagnostic Assessment: The Interface

With the harness attached, the diagnostic interface can be analyzed for total contact and determination of final trim lines. It is important to evaluate the load-bearing surfaces and ensure that forces are evenly distributed, so that excessive pressure is not applied to a single area. The diagnostic interface should be assessed while the patient is in various positions including standing, sitting, and trunk bending. Additionally, the diagnostic interface should be vertically loaded to ensure that it does not displace. Should changes be required to the diagnostic interface, they can be marked easily; the diagnostic interface can be placed back on the negative model and markings can be traced. Additional model rectification can be accomplished and the diagnostic interface can undergo localized heating. A wicking material and then a plastic bag are applied to the diagnostic interface, then a vacuum can be applied to re-contour the interface. Using this process, modifications can be made easily and quickly without producing an entirely new diagnostic interface. Please note, this process should be repeated as many times as necessary until a comfortable and total contact diagnostic interface is achieved.

Diagnostic Assessment: Controls

The control aspect of the diagnostic assessment focuses on the identification and verification of sufficient EMG signal recognition for myoelectric control, sufficient capture of excursion for cable-operated control, or both for hybrid control. When myoelectric control is selected, the diagnostic interface should be examined carefully for interface to skin contact, especially during contraction of the desired control muscles.[2] Often a volumetric re-contouring of the anatomy can occur during muscle contraction that results in a loss of interface to skin contact. Once total contact in the EMG site locations has been accomplished, electrodes should be mounted into the diagnostic interface and EMG signals should be verified. Please note, certain myoelectric systems require the patient to quickly co-contract antagonistic muscles to control certain functions such as unlocking the elbow or transferring control from terminal device to electric wrist rotator.3 Some patients have difficulty quickly contracting both targeted control muscles at this level and instead require either therapeutic intervention or an external switch.

When a cable-operated control scheme will be utilized, the interface should be evaluated for maximum range of motion to determine optimal excursion. Select a location on the interface that produces maximum excursion and attach the control cable, base plate locations, and corresponding attachment point on the elastic harness. The control strap attachment point is often located on the contralateral superior aspect of the elastic harness, capturing bi-scapular movement. The elastic harness can be reinforced with Dacron or similar nonelastic material from the control harness attachment point to the anterior aspect of the elastic harness for patients with narrow shoulders, limited range of motion, or for children. This allows the harness to be more efficient and capture maximum range of motion. Should this still be insufficient, an excursion amplifier can be integrated into the harness.

Diagnostic Assessment: Alignment

Once the controls at the interface level are sufficiently confirmed, the componentry can be mounted and aligned. Because the shoulder joint dummy location was determined as a part of the impression technique and incorporated during the model rectification process and diagnostic interface fabrication, mounting the shoulder unit at this point is facilitated. Evaluate the shoulder center location and the abduction/adduction and internal rotation angles by comparing them with the contralateral shoulder center. For the humeral neck level amputee, shoulder joint location can be a more complex procedure than simply mounting the shoulder joint at the matching level and angle of the contralateral shoulder. This will result in a cosmetic challenge, because the shoulder width of the affected side will be greater than that of the nonaffected side. A careful balance between function and cosmetic restoration is required. For patients with cosmetic concerns, often unilateral amputees, a solution to this issue is to mount the shoulder joint inferior to the distal aspect of the humeral neck.

Diagnostic Assessment: Fabrication Issues

Before fabricating the definitive prosthesis, the prosthetist should decide the following fabrication issues: material and thickness of interface, frame color and composition of lamination, frame trim lines versus interface trim lines, and permanent mounting of secondary control inputs. This is best accomplished while the patient is wearing the diagnostic prosthesis. The interface is best made of flexible thermoplastic material approximately 1/8 to inches in thickness. Often a window can be placed inferior to the shoulder joint on the lateral aspect of the interface, improving comfort by reducing heat build-up and weight. It is difficult to add a window to the diagnostic interface because it reduces the structural integrity of the thermoplastic and often results in loss of A/P rigidity. The frame should be constructed of carbon fiber using an I-beam technique. Creating an I-beam effect in the frame increases frame rigidity, producing a thinner, lighter-weight frame. An added benefit of an I-beam is that it creates a channel for wires to travel between the frame and the interface. The trim lines of the frame are usually to inches smaller than the trim lines of the interface, producing flexibility around the edges of the interface, improving comfort without sacrificing structural rigidity. Secondary control inputs can be mounted directly to the outside of the frame or recessed within the frame for a lower profile and more cosmetic appearance. It should be noted that the latter choice can result in some difficulty activating inputs through clothing.

Conclusion

The MicroFrame addresses the deficits of traditional interface designs, greatly improving comfort and stability. As discussed above, the impression technique for the MicroFrame is more complex, although model rectification is simplified and fit is far superior. The streamlined footprint that utilizes tolerant load-bearing anatomy (pectoralis major, infraspinatus, scapular spine, latissimus dorsi, serratus anterior, and scapular spine) for support reduces heat build-up to a great extent and eliminates tissue irritation associated with acromio-clavicular pressure. The musculoskeletal "lock" provides a more stable platform than shoulder-encapsulating designs, enhancing terminal device control and function for a number of reasons. Because the MicroFrame precisely contours to the anatomy without shifting, excursion for body-powered control is captured more efficiently and skin-to-electrode contact for myoelectric control is continuously maintained. Tissue irritation secondary to shifting of the interface is also greatly diminished. The musculoskeletal "lock" facilitates operation of a terminal device because positioning is more directly related to torso movement; this eliminates fatiguing compensatory gross body movement and decreases reliance on the contralateral limb. Finally, the removal of pressure from intolerant areas of the anatomy (the acromion) minimizes the perceived weight of a prosthesis, or the weight that the patient experiences, even though the majority of prosthetic weight (componentry) remains unchanged. As a result, heavier components, such as myoelectric elbows, wrists, and terminal devices, can be worn comfortably for extended periods of time (Figure 8). In contrast to the energy required to operate a body-powered prosthesis, myoelectric control improves function with much less effort. Consequently, the combined advantages of the MicroFrame enable individuals with glenohumeral disarticulation and associated levels of deficiency--a population that has historically experienced limited prosthetic success--to maximize their rehabilitation potential.

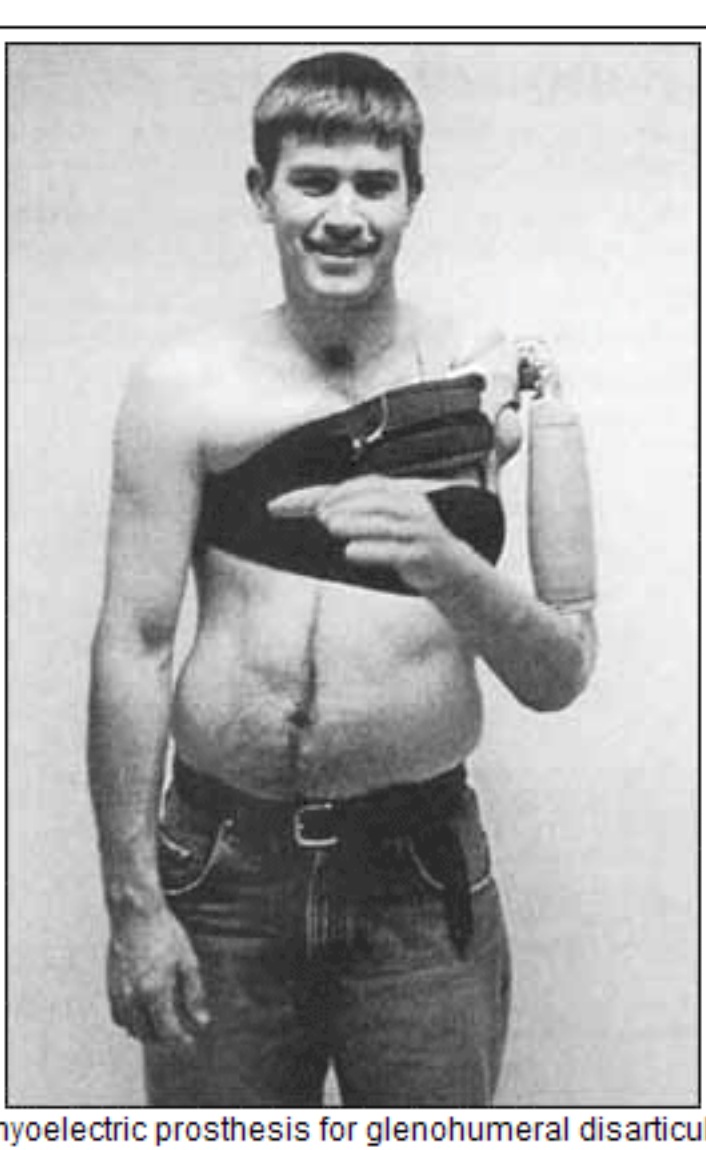
Figure 8. Definitive myoelectric prosthesis for glenohumeral disarticulation level amputee.

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