ADVANCEMENT OF UPPER EXTREMITY PROSTHETIC INTERFACE AND FRAME DESIGN
Randall D. Alley, B.Sc., C.P.
Hanger Prosthetics and Orthotics, Inc.

ABSTRACT
Although traditional upper extremity prosthetic interface and frame (collectively referred to here as “interface”) designs have enabled many individuals to integrate prostheses into their rehabilitation plan, the biomechanical attributes and other parameters of these designs have not been significantly reviewed and improved upon until recently. In the last decade, a multitude of design innovations have been incorporated, which have resulted in wearers reporting superior comfort, suspension, stability, and range of motion, among other advantages. In most cases, when paired with a variety of control systems, the new designs appear to be inherently more efficient in terms of force transmission and motion capture, and more functionally consistent than traditional types of “sockets”. It is the intention of this paper to highlight these novel design elements, as well as to discuss the biomechanical principles involved, to enable prosthetic users and other individuals to better understand these advanced interfaces.

INTERFACE DESIGN CRITERIA
The initial step in the improvement of an interface design is to first gain an understanding not only of the underlying functional intent of its constituent structures, but the resultant effect of these structures upon the critical elements responsible for successful prosthetic utilization.

The interface designs for three levels or degrees of absence will be discussed. These are the radioulnar (transradial), humeral (transhumeral) and the glenohumeral disarticulation and interscapulothoracic (shoulder disartic and forequarter, respectively) levels, the latter two incorporating essentially the same design, albeit with minor changes to auxiliary suspension. A brief comparison and contrast of both the physical and biomechanical properties of the traditional interface model with its more contemporary associate will be given.

RADIOULNAR

Traditional self-suspending interface designs at the radioulnar level typically focus on three distinct areas: 1) the supracondylar component; 2) the cubital component; and 3) the olecranon component. The soft tissue and skeletal anatomy distal to these regions are generally enclosed with a simple circumferential shape for volume containment. The ACC interface, in addition to these elements, adds a relief and modification to the antecubital region.

The Muenster design focuses on increasing anterior-posterior (AP) compression in the cubital fold. The Northwestern design focuses on increasing mediolateral (ML) compression proximal to the epicondyles. The Anatomically Contoured and Controlled (ACC) interface increases AP and ML compression but focuses them in different areas. In addition to the antecubital region described above, consideration is also given in the ACC interface to the distal humerus and the proximal portion of the extensor carpi ulnaris.

Comfort

The supracondylar component as addressed by the Northwestern design results in added suspension throughout the full range of motion, but also compresses the sensitive area over both the medial and lateral intermuscular septum, as well as the ulnar nerve and the medial antebrachial cutaneous nerve, hence negatively affecting comfort. The Muenster design utilizes AP compression...
primarily, but inherent instability can cause slight compression discomfort at the sensitive regions described above in dynamic situations. In both designs, a lowered anterior brim minimizes the effective lifting area of the forearm, and hence may increase lifting discomfort. The ACCI reduces compression in sensitive areas while concurrently increasing compression posteroproximal to the cubital fossa, and on either side of the antecubital relief, maintaining comfort while increasing suspension throughout the range of motion. In both the Muenster and Northwestern designs, the shape of the olecranon modification often creates shear stress and compression problems as the olecranon begins to displace toward the posteroproximal brim under flexion. The ACC interface modifies the shape of the olecranon relief to minimize or eliminate olecranon contact during ranging as well as donning and removal.

**Cosmesis**

Both the Muenster and Northwestern designs reduce the proximal extent of the anterior brim, and hence create a buildup of redundant tissue in the antecubital region with prolonged use. The ACC interface’s antecubital region prevents significant redundant build-up and its greater ML compression tends to more readily conceal its more extensive medial and lateral stabilizers.

**Stability**

In the Muenster and Northwestern designs, rotational stability is minimally provided due to the general absence of medial and lateral stabilizers. AP stability is often reduced during ranging and is often lost at full flexion as the olecranon displaces posteroproximally. In the ACC interface, the medial and lateral stabilizers significantly improve rotational stability. In addition, ancillary rotational resistance is provided by the modification of the antecubital area and displacement of the olecranon throughout the flexion range is minimized by the vertical segment of the interface proximal to the olecranon.

**Suspension**

Difficulties in achieving adequate suspension with the traditional designs arise in terms of either the discomfort of applied compression in sensitive areas, or the lack of adequate compression in non-sensitive areas. Additionally, the inclined olecranon relief typically permits translation of the residual limb out of the interface with the arm held over the head and the elbow joint is fully flexed. The ACCI focuses on maximizing compression in areas deemed suspensory and minimally sensitive. The olecranon modification inhibits displacement of the olecranon posteroproximally.

**Range of motion**

Both the Muenster and Northwestern interfaces address elbow flexion requirements by lowering (reducing the proximal extent of) the anterior brim. This increases the build-up of redundant tissue just proximal to the brim, which in itself is a primary inhibitor of full flexion. The ACC interface extends deeply into the cubital fold, while allowing a relief for the biceps tendon as well as the antecubital tissue to expand into during flexion. In addition, by significantly reducing the AP dimension, flexion is increased.
HUMERAL

The more traditional style focuses on basic volume containment along the humeral shaft and vertical loading over the shoulder complex via the proximal portion of the socket. Tom Andrew C.P.’s Dynamic Socket applies significant ML compression along the length of the humerus while lowering the lateral brim of the interface to a point between the axilla level and the acromion. In addition, anterior and posterior stabilizers are utilized. A derivative of the Dynamic Socket provides minimal ML compression distally while maximizing it proximally, and concentrates AP compression into a smaller area than can be found in the Andrews design.

Comfort

The most common complaint is this design’s over-the-shoulder style suspension, in which the socket rests on the superior surface of the humeral complex, and discomfort caused by this interface’s inherent instability. Both the Dynamic Socket and its hybrid cousin eliminate the interface contact on the proximal surface of the shoulder complex resulting in greater comfort during abduction and with increased heat dissipation.

Cosmesis

Inherent instability and proximal interface coverage reduce cosmesis in the traditional designs when the arm abducts or the ipsilateral scapula is elevated. Inherent stability in dynamic situations and reduced trim lines improve cosmesis in newer interface designs.

Stability

The newer styles utilize anterior and posterior stabilizers as well as ML compression, unlike traditional designs, to limit rotation in both the axial and sagittal planes.

Suspension

As previously stated, traditional humeral interfaces rest on the shoulder complex and occasionally on the trapezius in order to reduce vertical displacement under load. The newer designs utilize a shoulder saddle in most cases in order to achieve primary suspension. In addition, a secondary suspensory component is provided by AP compression anteriorly at the proximal overlap of the sternocostal and clavicular heads of the Pectoralis major, medial to the deltopectoral groove, and posteriorly at the level of the Infraspinatus.

Range of motion

In the traditional interface, range of motion is significant; however, stability at the extremes is precarious. The Dynamic Socket and its derivative simply reduce the medial projection of their anterior and posterior stabilizers to optimize the functional envelope while retaining a significant degree of stability in all planes and at the extremes of available glenohumeral motion.

GLENOHUMERAL DISARTICULATION AND INTERSCAPULOTHORACIC

A thoracic socket design that encloses and rests on the shoulder girdle is still the most common interface style used today. Also referred to as “basket-type”, “bucket” or “encapsulatory”,
this design has been used for decades. Newer interface designs rely on a frame-style approach, where only enough proximal, distal and medial projection is utilized to achieve adequate stability.

**Comfort**

Poor heat dissipation and discomfort from instability are the most obvious and negative aspect of traditional thoracic interfaces. Frame style interfaces such as the XFrame cover minimal tissue, and are significantly more stable. Similar to the humeral interfaces, the XFrame utilizes a discontinuous design which eliminates interface loading over the shoulder. The XFrame utilizes a large projection of thermoplastic distal to the laminated border than is currently used in other designs that greatly increases distal weight bearing comfort.

**Cosmesis**

Encapsulatory interfaces by nature are fairly cosmetic in the static anatomical position, yet become readily observable in the dynamic phase, where even subtle body motion typically results in frame displacements of large magnitude away from the body. The discontinuous feature of the XFrame inherently prevents vertical displacement above the shoulder during these movements.

**Stability**

Traditional interface stability is nebulous due to its significant coverage of a dynamically changing thorax and shoulder complex. Actions and reactions that occur within the frame secondary to gross body movement tend to leverage the socket off the body in a multitude of locations. This occurs because of the varying shape of the cross-sectional area defined by shifting contact points between the anatomy and the socket. In the newer frame-style interfaces, full volume containment is neither achieved nor desired, and as such stability is increased during gross body movement.

The XFrame is inherently more stable than other interface and frame designs in large part due to its geometry. Contact points provide rotational resistance in all planes, while the absence of a rigid transitional or suspending member over the trapezius prevents leveraging of the system off the body in response to gross body movements. Additionally, both superior and distal AP compression aids in restricting erratic motion of the frame in response to applied force.

**Suspension**

As mentioned previously, suspension in both encapsulatory and most frame-style designs is primarily achieved via a rigid socket or frame member extended over the shoulder complex or the trapezius. In the inherently unstable encapsulatory design, it tends to be its Achilles’ heel in regards to comfort.

In addition to a soft shoulder saddle, three additional suspensory elements are utilized in the XFrame when possible: 1) superior AP compression similar to that that utilized in the newer humeral interfaces described previously; 2) distal “hydrostatic” suspension over soft tissues (this also is utilized in some other frame-style interfaces); and 3) an additional scapulospinal element involving compression of the supraspinatus and the distal portion of the middle fibers of the trapezius.

**Range of motion**

It is important to discern between total range of motion, prosthetic range of motion and functional range of motion. A complete discussion of this is outside the scope of this paper. Inherently unstable designs may have excellent total range but are too unstable at the extremes to provide adequate function. The XFrame is stable at any and all ranges and therefore functional as well. The XFrame is the culmination of a long line of high-level frame designs that have been
utilized for individuals requiring the use of a prosthesis. It was developed as a direct response to significant weaknesses inherent in encapsulatory and other interface and frame styles, hence it borrowed from their basic design elements and from many of the individuals over the years whose work has preceded it. In clinical observations, the XFrame provides greater comfort, cosmesis, stability, and suspension while maintaining a smaller footprint and hence covering less surface area than more traditional designs.