THE Z-AXIS SHOULDER JOINT—A NEW CONCEPT

T. Walley Williams, III
Liberty Technology
71 Frankland Road, Hopkinton, MA 01748

ABSTRACT

It is difficult for a shoulder amputee to do anything while sitting at a desk or table with the elbow tucked in against the side. For useful work the elbow needs to move forward 30°-45° and out 30°-45° to a position of function. These moves require a well designed shoulder joint. Conventional friction joints are constrained to move about an abduction axis followed by a forward flexion axis with both motions against gravity. An ideal shoulder moves 'out' away from vertical and then locks. It then swings forward or back around the vertical Z axis with no gravitational constraint. Such a joint places the forearm in a convenient location for useful work.

WHAT IS THE FUNCTION OF A SHOULDER JOINT

Traditionally prosthetists treat the shoulder joint almost as an afterthought. This is because without power assist prosthetics can do very little to replace any arm functions at the shoulder disarticulation level. Further there is a tendency to let the anatomical terms 'forward flexion' and 'abduction' color one's thinking about the shoulder joint and its function. A typical passive shoulder joint has separate hinge action for forward flexion and abduction. Each is able to have some friction added and there is usually a stop that limits extension when the upper arm is straight down. This may not be the best approach.

To find a new approach we need first to think of the arm system in anatomical terms and then immediately to shift to engineering terminology. The hand grips and manipulates, the wrist orients the hand, the elbow controls how close to the shoulder the hand lies, and finally the shoulder orients the arm and controls one of the orientation angles of the forearm (internal/external rotation). The most important functions are those of the shoulder joint. If the upper arm and forearm are not oriented correctly, no useful work can be done by the most sophisticated electric elbow and terminal device. It is almost impossible to do anything constructive while sitting at a table or desk with the elbow tucked in against the side. The 'position of function' is with the elbow 30°-45° out and 30°-45° forward.

WHICH ROTATION AXES ARE BEST

The natural shoulder is a ball-and-socket type joint with three degrees of freedom. We will dispose of humeral rotation first, because this rotation about the long axis of the upper arm is not arbitrary. It can be controlled or locked or friction can be provided either at the shoulder or elbow end of the upper arm, but this motion is constrained to be about the long axis. In most prostheses this rotation is placed just above the elbow and is part of the elbow mechanism.

The remaining two axes for moving the elbow in space are arbitrary, and we can choose them in any way that suits us. In particular we can reject the anatomical terms 'forward flexion' and 'abduction' and look for good engineering reasons to select other rotation axes. It is important to think of the rotation axes as hinges. And one of the two hinges must always be attached to the shoulder and act first. When it acts, it rotates the second axis to a new orientation. Thus while one can multiply numbers in any order and still get the same answer, it matters what order one picks when doing rotations as will become apparent below. Let's start with the arm fully extended along the side. One can then 'flex' the elbow, 'forward flex' the arm or 'abduct' the arm. In each case the result will be prosthetically useless with an artificial arm unless the forces of gravity are resisted. Thus the engineer is free to choose the angle with respect to *vertical* as one of the two rotation angles. We will call it the 'out' angle. The other angle we can call the 'swing' angle.

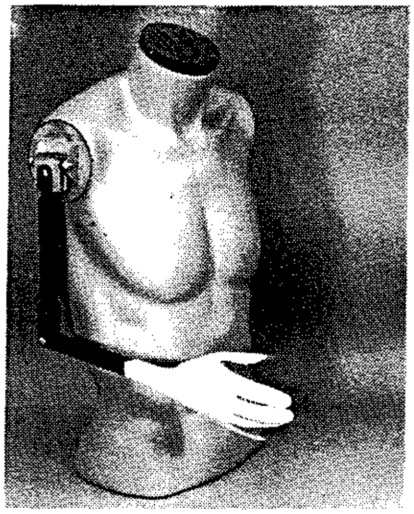

Figure 1. Before: Elbow flexed 90°.

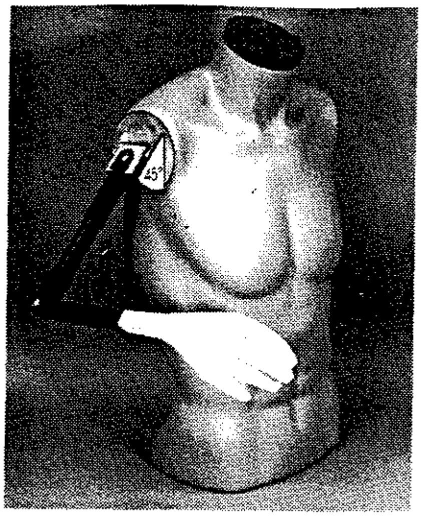

Figure 2a. Hosmer: Out 45°, forward 0°.

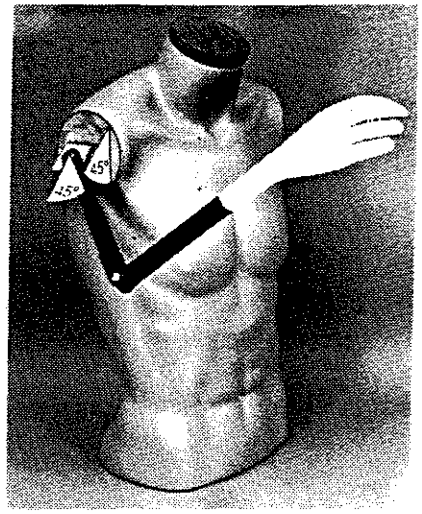

Figure 2b. Hosmer: Out 45°, forward 45°.

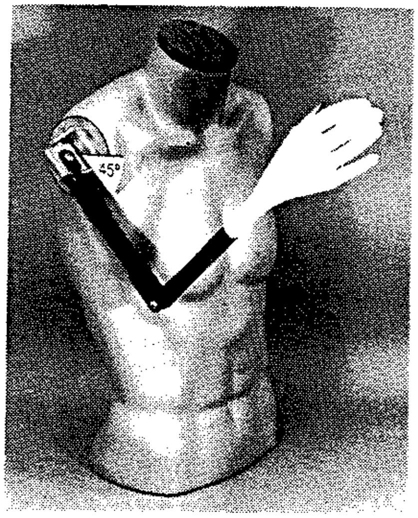

Figure 3a. MICA: Forward 45°, out 0°.

Figure 3b. MICA: Forward 45°, out 45°.

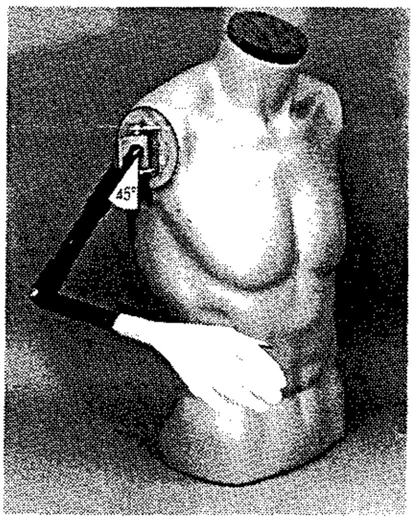

Figure 4a. Z-Axis: Out 45, Swing 0°.

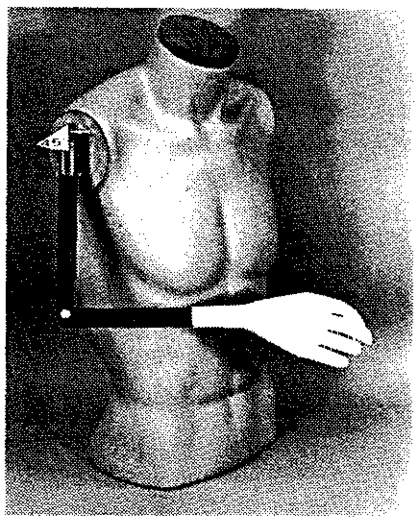

Figure 4b Z-Axis: Out 45°, swing 45°.

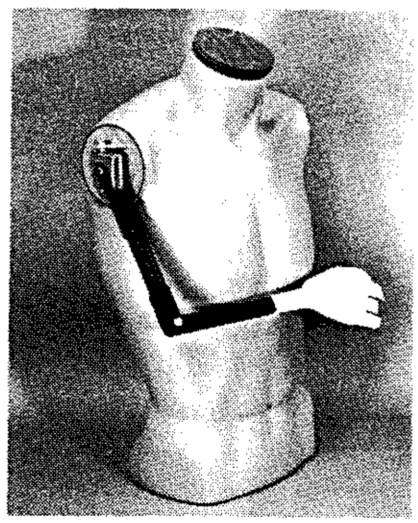

Figure 4c Z-Axis: Out 45°, swing 80°.

It defines motion about the vertical or Z axis. In a practical joint Z-axis rotation occurs first, and it defines the angle of the axis for the out rotation. Only this rotation is against gravitational forces.

How Rotations Affect the Forearm

To illustrate how the selection of rotation axes affects the orientation of the forearm, a mock-up shoulder and arm have been attached to a mannequin to illustrate the affect of three types of shoulder joint on forearm position. In the first, abduction occurs before forward flexion. In the second, forward flexion is first. Finally, in the third set of photos, out is first followed by forward swings about the Z axis of 45° and 80°. Each set of photos involves two rotations, each of 45.° The first two sets are identified by their most popular embodiments, the Hosmer FAJ-100 Friction Joint and the MICA Locking Shoulder, while the lsat is simply called the Z-axis joint

Both the MICA and Hosmer rotations place the elbow in exactly the same position in space; however, the forearm ends up oriented quite differently. In Figure 2b The hand ends up in front of the shoulder joint pointed upward and forward at 45°, while in 3b the forearm is pointed straight forward and up out to the side. Neither of these forearm locations are useful for much without an internal rotation which is normally accomplished against friction. The Z-axis joint, however, places the forearm parallel to the floor or a table, in front of the body, and partly pronated as can be seen in Figure 4b. Very little further adjustment needs to be done to accomplish useful work. Figure 4c shows how further inward rotation about the Z axis brings the forearm across the centerline. This is normally a difficult position for shoulder amputees to achieve.

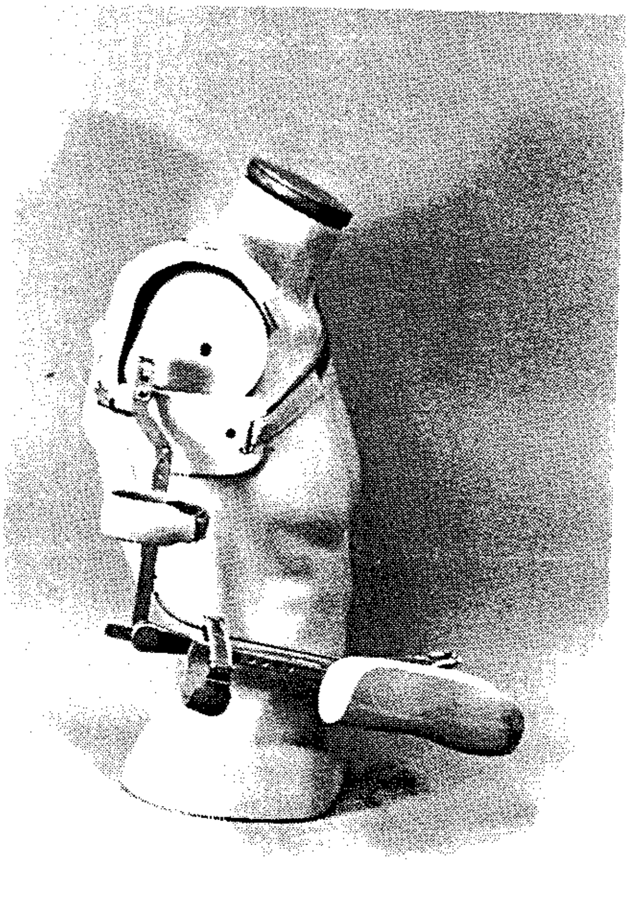

Figure 5a. The Steeper Stanmore flail arm joint permits three hinge motions:

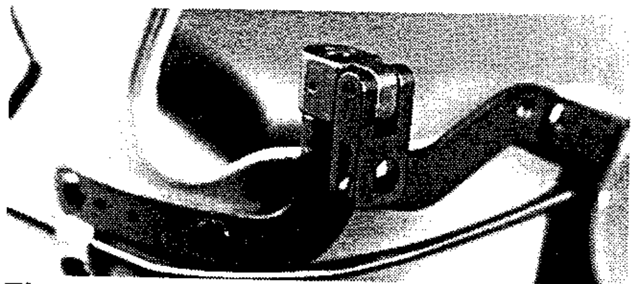

Figure 5b. Forward flexion.

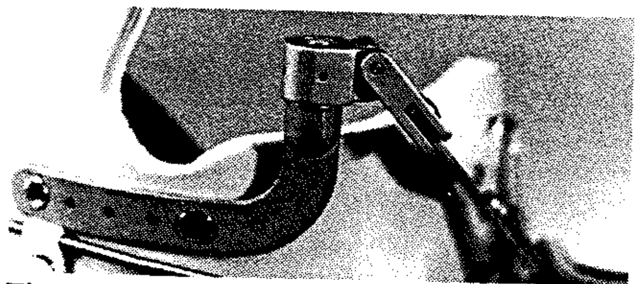

Figure 5c. Forward swing.

Figure 5d. Movement out.

Z-AXIS SHOULDER JOINTS

One Z-axis joint already exists. It is the joint H. Steeper, Ltd. markets as part of the Stanmore flail arm splint. It is shown in Figure 5 with closeups of the joint in three positions in Figure 6. Unfortunately this joint has no provision for opposing motion in the in-out direction. Tom Andrew (personal communication) has altered this joint to introduce friction, but success has only been moderate because the parts are small limiting the moment arm of the clamping member.

Z-Axis Joints and Gravitational Torques

A Z-axis joint has one particularly appealing feature—only one rotational motion is opposed by gravitational torques. This fact makes it worthwhile addressing two issues. First one should consider opposing the torques produced by the prosthesis itself and second one should consider a rotation lock that is easy for the user to activate.

Rotation about the Z axis only has a gravitational component when the user leans forward or back. Thus this joint can be secured by a moderate amount of friction supplemented by detents.

The author is currently working on a shoulder joint that will compensate for the weight of the prosthesis and will also have a convenient locking and unlocking arrangement.