INTRODUCTION

Management of high-level bilateral amputees poses a significant challenge for the treating parties. Selection of the most appropriate prosthetic components and controls requires knowledge of the many options available and the ability to predict which systems will most benefit the user. Long-term follow-up of these individuals is rarely reported. Through retrospective study it may be possible to identify attributes of prosthetic systems that have been successful and incorporate those attributes in future systems. This paper outlines the prosthetic management of an individual, KF, with traumatic bilateral shoulder disarticulation amputations over a nineteen-year period.

In 1986, the Prosthetic/Orthotic Clinical Service Department of the Rehabilitation Institute of Chicago (RIC) and the Rehabilitation Engineering Research Center (RERC) in Prosthetics and Orthotics of Northwestern University began a collaboration to improve the prosthetic fitting of persons with higher-level bilateral amputations. By the time of KF’s admission to the RIC, a hybrid fitting concept had been developed using body-powered and electric-powered components in a complementary manner to enhance the function of the total prosthetic system [1,2]. Cable-actuated body-powered components were used on the dominant side to take advantage of the physiological proprioceptive feedback intrinsic to cable control. This prosthesis was used primarily for fine positioning and dexterous object handling and manipulation. Electric-powered components were used on the non-dominant, or assistive, side to provide higher gripping forces and greater lifting torque.

INITIAL FITTING

KF was fit with a complete body-powered system on the right side and a socket without prosthesis on the left side in October 1989. The prosthesis included a 5XA split hook (Hosmer Dorrance), a Sierra Wrist Flexion Unit (Hosmer Dorrance), a locking Rotation Wrist (USMC), an E-400 Elbow with friction turntable (Hosmer Dorrance), and a friction FAJ shoulder joint (Hosmer Dorrance). The lock control cables of the E-400 elbow and the Rotational Wrist were routed to modified Sierra Nudge Controls (Hosmer Dorrance) mounted to the socket for chin actuation. The lock control lever of the Sierra Wrist Flexion Unit was extended so that it could be actuated against KF’s thigh or knee or engaged against an object in the environment.

Biscapular abduction was used to open the fingers of the split hook, rotate or flex the two wrist components, or flex the elbow using a single positioning control cable. The route of the control cable from the lateral-mounted forearm lift tab to the attachment post of the split hook passed the cable medial to the axes of rotation of the Rotational Wrist and the Sierra Wrist Flexion Unit. If the Rotational Wrist was unlocked, biscapular abduction pulled the wrist into supination. Relaxing the control cable allowed a spring to pull the wrist into pronation. If the Sierra Wrist Flexion Unit was unlocked, biscapular abduction pulled this component into flexion, and relaxing the cable allowed an elastomeric band to pull it into extension.

A pulley was set up as an excursion amplifier to double the range of cable travel. Spectra cable (TRS) and Teflon-lined housing were used to reduce friction losses.

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Laminated frame type sockets with carbon fiber reinforcement were used to spread loads over a large area yet expose as much skin as possible for improved ventilation [3]. The sockets were designed to capture as much bicipital motion as possible and provide rotational stability in order to maximum function with the prostheses.

In December 1989, KF was fit with the left complementary prosthesis [4]. This prosthesis included the electric-powered Greifer (Otto Bock), the Electric Wrist Rotator (Otto Bock), the electric-powered Boston Elbow with friction turntable (Liberty Mutual), and a friction FAJ shoulder joint. The Greifer and Electric Wrist Rotator were controlled with separate chin-actuated Rocker Switches (Otto Bock) mounted to the socket. The Boston Elbow was controlled with a two-function Harness Pull Switch (Otto Bock) actuated by shoulder elevation. The frame socket on the left side had been modified with a superior cutout so that the clavicle and scapula could be raised through the opening. The switch was mounted to the anterior of the socket below the cutout with a section of harness webbing passing from the switch, over the shoulder, and anchored to the posterior of the socket.

UPGRADES AND CHANGES

No prosthesis should be considered the definitive or final prosthesis. Each major repair or replacement is an opportunity to reevaluate the client’s functional goals and re-consider the design of the prosthesis in light of improved fabrication techniques and materials and new components and control schemes.

The hybrid design concept implemented in KF’s 1989 prostheses proved to be both functional and versatile and was retained in each refitting. There have, however, been many changes, beginning with replacement of the right FAJ friction shoulder joint in 1991 with the, then, newly available MICA Locking Shoulder Joint.

The friction shoulder joint had been a source of frustration with the friction either too low, causing the shoulder to slip position when KF was trying to push with his prosthesis, or too high, making pre-positioning arduous. The MICA shoulder joint could be locked at 18° intervals in flexion and extension, although abduction/adduction was still friction-based. When unlocked, the joint would swing freely with trunk rotation or bending. Furthermore, the MICA joint allowed the arm to be positioned and locked over head; whereas, the FAJ joint was limited to 90° of forward flexion. A cable unlocked the MICA joint through a modified manual knee lock control (Blatchford) adapted for chin actuation. The MICA joint required more frequent maintenance than the Hosmer FAJ joint. However, the functional advantage of a locking shoulder joint was far greater than this inconvenience, and KF opted to have a locking joint retrofit to his second left prosthesis in 1992.

In 1994, a third left prosthesis was fabricated and the switch-actuated Boston Elbow was replaced with the Boston Elbow II (Liberty Technology). The control arrangement for the elbow and Greifer were also changed at that time. The earlier method of operating the Greifer with a chin-actuated Rocker Switch prevented KF from seeing the Greifer while controlling it when it was above his head. This conflict only arose as a consequence of incorporating the MICA shoulder joint. The control was changed so that shoulder elevation against the Harness Pull Switch operated the Greifer. The chin-actuated Rocker Switch, previously used for the Greifer, was replaced with two force sensitive Touch Pads for control of the elbow. The force of pressing on the Touch Pads proportionally controlled the speed of the faster Boston Elbow II.

Control of the Greifer was again changed in 1997. The Harness Pull Switch was replaced with a Linear Actuator (Liberty Technology). With this arrangement, the degree of shoulder elevation determined the speed of the Greifer or the rate at which grip force changed.
The next major change was replacement of the friction turntables (for humeral rotation) with locking HR Units (Rimjet). These devices could be locked at 22.5° intervals. Replacement was done on the right prosthesis in 1998 and on the left prosthesis in 1999. Replacement on the left prosthesis required a custom adapter to couple the HR Unit to the Boston Elbow II. The HR Units on both sides were unlocked using chin-actuated Sierra Nudge Controls.

Figure 1. Anterior and posterior views of the 2006 set of hybrid bilateral prostheses.

Figure 2. (A) Arrangement of chin-actuated Nudge Controls for the locks of components of the right prosthesis. (B) Arrangement of chin-actuated lock controls, chin-actuated Touch Pads, and shoulder-actuated Linear Actuator for components of the left prosthesis.

The most recent upgrade was done in 2006 when another set of new prostheses was fabricated (Figures 1 and 2). On the right side, the Sierra Wrist Flexion Unit and Rotational Wrist were replaced with the lighter N-Abler V Five Function Wrist (Texas Assistive Devices). Actuation of the rotation and flexion locks remained the same – chin-actuated nudge control for rotation and an extended lock release tab for flexion.
On the left side, the Boston Elbow II was replaced with the more versatile Boston Digital Arm System (Liberating Technologies). The Greifer was replaced with the ETD (Motion Control) because of KF’s preference for hook-type fingers. The Electric Wrist Rotator was retained but converted to proportional control with replacement of the chin-actuated Rocker Switch by two chin-actuated Touch Pads.

Although many individual changes have been made within the hybrid prostheses, overall, the design has moved toward all locking components on both the body-powered and electric-powered sides and all proportional control on the electric-powered side. Locking components are easier to pre-position (than friction components) when unlocked and, when locked, make the prosthesis a rigid extension of the body through which high forces can be exerted on objects in the environment. Proportional control of electric-powered components, particularly higher performance components, generally improves their controllability and, consequently, their functional benefit. Reliable and repeatable control is especially important in the absence of any direct proprioceptive sense of the action of the electric component and reliance on vision.

FUNCTION AND ADLS

Within the first year after bilateral fitting KF was able to independently don and doff the prostheses and perform routine activities of daily living including; bathing, toileting (with bidet), simple meal preparation and feeding [4]. Today KF performs many tasks such as driving his truck, yard maintenance including driving a riding mower, driving a tractor, and loading and unloading the tractor on a flatbed tilting trailer. All of these tasks are performed independently on a routine basis.

CONCLUSION

Experience gained from this fitting and other high level bilateral fittings has demonstrated that a hybrid approach combining body-powered and electric prostheses has merit [5,6]. Body–powered prostheses offer proprioceptive feedback through the cable and harness and are therefore favored for fine manipulation by users of hybrid prostheses similar to those described. Electrically powered prostheses offer higher grip strength and greater live-lift capabilities and are favored for activities that require those features. The most important variable in fitting the high-level bilateral arm amputee is the user. Persons with the ability to problem solve and with the determination to master the use of their prostheses can achieve a remarkable level of independence.

REFERENCES