A MODULAR SOLUTION TO A UNIQUE DESIGN REQUEST FOR A SHOULDER DISSARTICULATION PROSTHESIS: A CASE STUDY

Heather Daley, CP, Wendy Hill, OT, Dan Dafonseca, RTP

Atlantic Clinic for Upper Limb Prosthetics, Institute of Biomedical Engineering, UNB

ABSTRACT

This case study details the development of a customized myoelectric prosthesis for a patient with a modified shoulder disarticulation level amputation, focusing on the integration of a novel detachable arm feature to enhance user comfort and functionality. By employing additive manufacturing technology and innovative design strategies, a prosthetic solution was crafted to meet the specific needs of the patient, including prolonged wear and ease of use with the most notable quick-disconnect mechanisms. The resulting prosthesis not only fulfilled the patient's request for a modular, lightweight arm but also significantly improved his quality of life by allowing for greater flexibility, versatility, and adaptability in daily activities. This work demonstrates the potential for tailored prosthetic solutions to address complex challenges, highlighting the importance of patient-catered design choices in the field of prosthetics.

INTRODUCTION

Shoulder disarticulation level amputations, constituting only 3% of all traumatic amputations, present distinct challenges in terms of prosthesis fitting and functionality [1]. Unlike more common amputations such as transradial or transhumeral, the limited availability of control sites at the proximal level poses a unique obstacle for achieving optimal functionality in prostheses for shoulder disarticulation amputees. Brachial plexus injuries further complicate matters, as they restrict the use of distal muscles as potential control sites for the prosthesis [2].

Functional prostheses at this level tend to be heavy, bulky, and require control options to operate multiple joints including shoulder, elbow, wrist, and hand motion. Body-powered prostheses for this proximal type of amputation are generally not accepted by patients because of the complexity of cable control for multiple joints and the limited functional grasp given the amount of effort required to activate a terminal device[3]. Body movements required for this level include scapular protraction, retraction, elevation, and rotation which can be particularly challenging or impossible, especially after a brachial plexus injury.

In response to these challenges, powered prostheses emerge as a viable solution for shoulder disarticulation amputees, offering increased functional gripping power with reduced effort from the body [4], [5]. The use of powered prostheses becomes crucial in addressing the limitations associated with body-powered alternatives, providing a more user-friendly and efficient option. This case study outlines a unique design of a powered prosthesis with modular arm sections to meet the functional needs of the patient. The modular design allows for customization and adaptability, addressing the unique complexities associated with this level of amputation and enhancing the overall usability and functionality of the device.

MEDICAL AND PROSTHETIC HISTORY

TC experienced a workplace accident in 1988 when his arm got caught in an industrial bread mixer which resulted in a brachial plexus stretch injury and spasmodic torticollis. After extensive rehab and several surgeries to improve range of motion and hand function, he eventually elected to have his arm amputated at a modified shoulder disarticulation level four years after his original injury. Before his amputation, he experienced significant chronic pain, weakened muscles in the neck and shoulder area, and a non-functional and insensate arm. Due to the high-riding scapula, a major muscle release procedure including trapezius and levator scapulae muscles was performed in conjunction with amputation. The humeral head remained intact. The surgical outcome successfully improved TC's shoulder and neck positioning, enhancing his overall posture. Nevertheless, he continued to experience pain, weakness, and a diminished range of motion in his neck post-surgery.

Following the injury, TC sought care at a different prosthetic clinic for several years. It was at this clinic that he acquired his initial powered prosthesis, which featured a linear transducer for hand open/close control. In an effort to alleviate the burden of the heavy arm while keeping his socket on, TC requested the detachability of the humeral section of the prosthesis. Unfortunately, the clinic expressed skepticism about its feasibility due to the incorporated electronics. Subsequently, TC returned home and took matters into his own hands. He ingeniously incorporated a seatbelt buckle into the shoulder joint and wired an auxiliary ¼" jack to the linear transducer cable, allowing for easy detachment (Fig. 1). This inventive solution not only addressed his desire for a detachable humeral section but also showcased TC's resourcefulness in enhancing the functionality and comfort of his powered prosthesis.

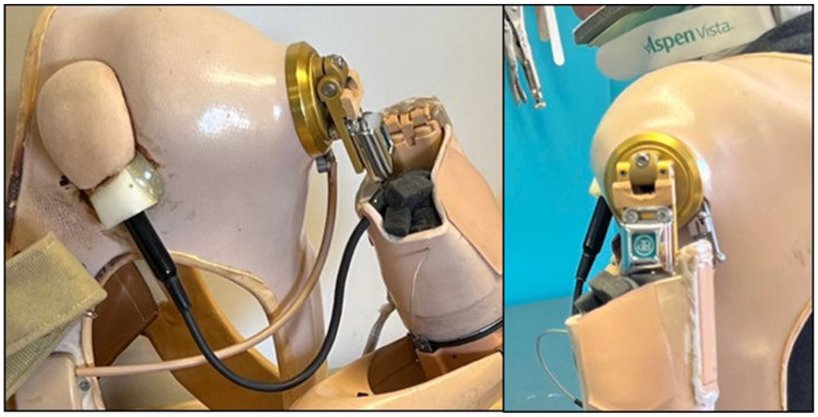

Figure 1: TC's initial adapted powered prosthesis featuring an integrated seatbelt buckle in the shoulder joint and an auxiliary ¼" jack for convenient detachment of the humeral section. This inventive modification was implemented by TC at home to alleviate weight and relieve pain while keeping his socket on.

In 2009 TC received his second powered prosthesis from our clinic with an improved socket design and upgrades to the electronic connections. He returned to our clinic in 2022 requesting a new prosthesis. His previous arm was no longer fitting properly, and the electronics had failed. During our consultation we discussed socket design, materials, terminal devices, and control strategies. TC emphasized his priorities for the design, which included a lightweight structure, a shortened forearm, and a removable arm segment. Our decision to accommodate this request was driven by two primary factors. Firstly, recognizing TC's strong preference for a removable arm, we anticipated that he might attempt self-modifications if not provided with this feature. Secondly, we recognized the intrinsic value of this modification for enhancing his ability to engage in functional activities with reduced pain. Thus, our aim was not only to meet TC's immediate needs but also to contribute to his long-term comfort and functionality.

In order to accomplish this, we needed an easy-to-use locking mechanism that incorporated an electronic pass through, while being able to don and doff without visual feedback due to the limited range of motion in his neck, so that the arm could be removed and reconnected in one swift motion without adding any extra steps for reconnecting electronics.

PROSTHETIC TREATMENT

A lightweight hybrid silicone socket was fabricated with pre-preg carbon-fiber for strength and flexibility. We also incorporated a wide custom silicone axilla strap to distribute the forces and improve comfort. After trials and demos of various components, we decided an Ottobock Ergoarm Hybrid Plus, ETD2, and TASKA hand would best meet his functional needs, with a linear transducer for single site control using chest expansion for excursion. With the use of magnetic Fidlocks, including a boa style Fidlock for the linear transducer cable, this also made donning and doffing far easier than traditional Velcro or buckles.

Designs were drafted for a humeral component that bisected the Axis shoulder joint and the Ottobock elbow joint as the detachable location. This also had to contain the electronic passthrough and lock mechanism all in one unit, while components such as batteries and other heavy parts had to be housed in the detachable portion of the arm. The manufacturing method of choice became 3D printing with the lightest and strongest material available to us at the time, a carbon fiber reinforced Nylon 12 filament (PA12 CF). After several iterations, Fuse Deposition Modeling (FDM) printed PA12 CF worked well as it consequently had a coarse surface finish which bonded well to the carbon fiber lamination done over the printed parts. A carbon-fiber lamination was necessary to ensure appropriate levels of strength.

This 3D printed design involved non-variable conditions: Locking quick disconnect, anti-rotation, electronic pass through, as well as swift and easy one-handed operation for attachment/detachment. The lock integrated in the design was a smooth pin Icelock 651, and the electronic junction was a spring-loaded pin style connection. Numerous iterations of the modular system were tested with multiple diagnostic fitting stages until a final device was produced (Fig 2).

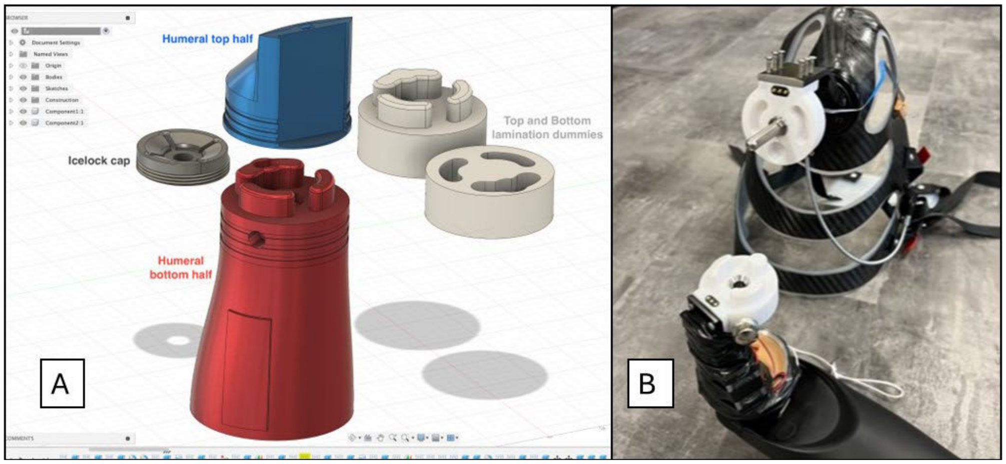

Figure 2: Design process for humeral disconnect. A) CAD drawings B) trial on test socket with components in place

During one of the socket trials, TC mentioned that a second shortened arm segment without an elbow would be useful for some of his applications when using power tools at shoulder level. He also mentioned there were times, especially for doing yard work, that he required a secure grasp with a quick release for tools such as a snow blower, lawnmower and weed trimmer. This conversation led to the design of two additional arm segments (one powered and one passive) that could be used interchangeably with his prosthesis. The final device is shown in Figure 3 below.

Figure 3: Final Prosthesis with three interchangeable arm segments

OUTCOME

The result of this fitting was the creation of a prosthetic device that fulfilled all the patient's criteria: lightweight, flexible, comfortable, and functional. The interchangeable arm segments, designed to address diverse needs, provided significant value. Now, he can maintain his socket for extended periods, thanks to the convenience of the quick-disconnecting arms. Embracing the versatility of his three modular fitting arms, he seamlessly incorporates them into various activities. However, a challenge emerged after several months of use related to the smooth pin lock. The continuous exposure to high vibration power tools led to a gradual loosening of the smooth pin lock, almost resulting in an electronic connection loss. To rectify this issue, the smooth pin Icelock was replaced with the same format ratcheting style Icelock 621.

Through the application of additive manufacturing and an open mind, this project successfully addressed the unique challenges presented by the patient's needs, emphasizing modularity, comfort, and function. The process involved numerous trial fittings and design iterations, particularly in refining the locking mechanism. The final prosthesis significantly improved the patient's quality of life.

*Figure 4: Training with prosthesis A) using power tools as he would at home and B) doing meal prep. *Written consent was obtained for the use of the photos in this paper.*

This case demonstrates the potential of tailored, iterative development processes in advancing prosthetic function and patient satisfaction. The success of this device reinforces the value of continuous improvement and patient involvement in developing prosthetics that not only meet but exceed user expectations.

REFERENCES

[1] T. R. DILLINGHAM, L. E. PEZZIN, and E. J. MACKENZIE, “Limb Amputation and Limb Deficiency: Epidemiology and Recent Trends in the United States,” *South Med J*, 2002, doi: 10.1097/00007611-200208000-00018.

[2] Dr. A. U. S, Dr. D. T. E, and Dr. A. F. E, “Damn Nuisance from brachial Plexus Injury, An Uncommon Indication for Shoulder Disarticulation,” *SAS Journal of Surgery*, vol. 8, no. 5, 2022, doi: 10.36347/sasjs.2022.v08i05.011.

[3] B. Petersen, “Amputations about the shoulder: Prosthetic management,” in *Atlas of Amputations and Limb Deficiencies*, Fourth., vol. 1, I. Krajbich, M. Pinzur, B. Potter, and P. Stevens, Eds., Rosemont: American Academy of Orthopedic Surgeons, 2016, pp. 287–298.

[4] R. D. Lipschutz, B. Lock, J. Sensinger, A. E. Schultz, and T. A. Kuiken, “Use of two-axis joystick for control of externally powered shoulder disarticulation prostheses,” *J Rehabil Res Dev*, vol. 48, no. 6, 2011, doi: 10.1682/JRRD.2010.08.0161.

[5] R. D. Lipschutz, T. A. Kuiken, L. A. Miller, G. A. Dumanian, and K. A. Stubblefield, “Shoulder disarticulation externally powered prosthetic fitting following targeted muscle reinnervation for improved myoelectric control,” in *Journal of Prosthetics and Orthotics*, 2006. doi: 10.1097/00008526-200604000-00002.