"INTEGRATING NOVEL COMPONENTS INTO BILATERAL PEDIATRIC SHOULDER DISARTICULATION PROSTHETIC FITTINGS: A CASE STUDY."

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ABSTRACT

Pediatric amputees (both congenital and acquired) with above elbow limb loss have extremely limited prosthetic options. This often results in abandonment or no opportunity to use a prosthesis in childhood. In the absence of appropriately sized, commercially available components, repurposed and custom components were integrated in a series of fittings with a four-year-old patient with bilateral limb deficiencies at the shoulder disarticulation level. These included elbowless initial body powered prostheses, progression to 3D printed ratcheting elbow joints and repurposing of an electric wrist flexion unit as an electric pediatric elbow. Progressive enhancements to the prosthetic treatment plan led to increased prosthesis utilization and independence. Additional pediatric component options, especially electric components, are needed to address proximal limb deficiencies in these younger children.

INTRODUCTION

A recent retrospective analysis observed a prevalence of 23.5 congenital upper limb anomalies per 10,000 live births [1]. Of the 10,700 reported cases in this series, only 6 presented with complete congenital absence of one or both upper limbs [1]. Children with bilateral proximal upper limb congenital deficiencies find ways to adapt to the dexterous world around them [2]. They often surpass their abilities to function with traditional prostheses by compensating with alternative body mechanics to achieve their goals; thus making traditional body powered prostheses less valuable and irrelevant in regards to the majority of their activities of daily living. This case describes a series of prosthetic fittings for a 4-year-old female patient with congenital bilateral shoulder disarticulation, integrating both custom and repurposed components to facilitate increasing function.

PATIENT PRESENTATION

The patient presented with bilateral congenital limb deficiency at the shoulder disarticulation level at age 4. She had never been fit with prostheses as her family had been advised that there were no prosthetic options available that would make her more functional. With the expectation of starting kindergarten next year, there were several functional tasks that the patient, family, and therapist hoped she would be able to achieve with greater independence. At the time, the patient was extremely functional with her feet and incredibly determined to do everything independently. However, there were tasks that could not be completed efficiently or safely with her feet in which assistance would be required. Furthermore, she was diagnosed with hip dysplasia that required surgical intervention and left her with a leg length discrepancy. Otherwise, the patient was a healthy, lively, and strong willed 4-year-old girl.

INITIAL BODY-POWERED PROSTHESES

Recognizing the insurance limitations in the United States, a plan was made to initially provide body-powered devices to determine their functional impact. These initial body powered prostheses were fabricated as bilateral units (Figure 1). Pediatric Ottobock shoulder joints were directly laminated to "shoulder cap" style sockets with flexible inner liners. These friction shoulder joints allowed for pre-positioning in the sagittal plane. There was no elbow joint. Instead, a tube-shaped arm was laminated to a delrin wrist unit, where pediatric nylon coated hooks were fastened. The harness consisted of a single strap across her chest anteriorly, and elastic webbing that formed an "X" to connect the two sockets to one another in a criss-cross formation on her back. Control cables ran from her prosthetic hooks to the posterior distal aspect of the contralateral socket with housing retainers positioned at the approximate position of the elbows. With this configuration, the patient open the hook with scapular protraction and close the hook with scapular-retraction.

Figure 1: Initial body powered prosthesis

The initial impact of these devices was extremely positive. The patient was immediately able to open and close the hooks and she was soon able to donn and doff them independently. While they boosted her confidence, over time she learned of their many limitations. First, only one hook could be opened at a time due to the opposing forces on her back. This limited any chance at bimanual prehensile activities. Second, in the absence of an articulating elbow she could not lift the forearms to bring her hooks towards her mouth preventing her from feeding herself with her prosthetic hooks. Third, the amount of force experienced the anterior portion of the sockets with the excursion required to open her hooks caused much discomfort. Eventually the patient grew fatigued with the intensive effort required to use the prostheses and lost interest in them.

A second set of prostheses were later made to improve upon this design (Figure 2). The sockets were changed to "X Frame" designs to reduce localized pressure and improve comfort. The shoulder joints were replaced with universal ball and socket shoulder joints which allowed for friction resisted rotation, abduction/adduction and flexion/extension. Custom ratcheting elbow joints were 3D printed to connect the shoulder component to the wrists and hooks. The elbow joints could be passively positioned into various flexion positions. The locking cable was tied into a plastic tube that was routed along the anterior socket and towards the patients mouth so that she could bite and pull the tab cycle the elbow lock. The delrin wrists were replaced with passive flexion wrist units so that her hooks could be prepositioned for better access to midline reach. The hooks were cabled in a similar fashion to the previous prostheses.

Figure 2: Subsequent endoskeletal body powered prosthesis

Several functional improvements were observed with this second set of body powered prostheses. The force redistribution within the X frames reduced pain. The patient was able to unlock the elbow position with the bite straps but struggled to lock it again. While she required assistance to position the elbows, the family was happy that they could at least change the elbow position. Unfortunately, this socket set up required two straps for donning and doffing. While the patient was still able to do this independently, it increased the time and concentration for applying the prosthesis. She was still unable to operate both hooks at the same. Improvements included holding a wider object at waistline, carrying a bag over her forearm while walking, holding light weight foods in her hook which have been pre-positioned at her mouth, pushing open a door without having to use her feet and pulling large objects across the floor. Notably, the majority of the patient's activities could still be done faster with her feet.

Despite the functional gains that the prostheses provided there were limitations with both devices. The prostheses were bulky and changed her natural proprioception and understanding of spatial awareness. They took a lot of time to put on and take off independently and only provided her with a few functions. She would prefer to take the prostheses off in between functions while she was not needing them. Since the functionality was limited, this could mean between 15 minutes to several hours of time in between use. Over time the patient learned that she would rather ask for help or attempt to preform activities with her feet because it was faster and more efficient than to stop what she was doing to put the prostheses on and have someone preposition them for her.

MYOELETRIC PROSTHETIC INTERVENTION

Having established the limitations of body-powered designs for this patient, a myoelectric device plan was made. A unilateral left prosthesis was fabricated with a Sauter style socket (Figure 3). This allowed for the least amount of enclosed tissue and skin contact while maintaining a very stable socket fit. The proximal part of the socket, which contoured over her left shoulder provided vertical suspension. Medial suspension was provided by a single strap. A flexible inner socket was used to allow for adjustments of pressure and fit without disrupting the structural integrity of the socket frame. The Hosmer adult shoulder joint was turned upside down to better fit the small profile of the patient and the shape of the socket frame. The metal strut was contoured to fit the humeral section and provide protection to electrical wiring. The humeral section was laminated and left with a hollow opening. A delrin wrist was laminated to the distal end of the humeral section to provide a connection point to the elbow. Unfortunately, a pediatric myoelectric elbow is not available on the prosthetic market. Instead, a Motion Control powered wrist flexion unit was utilized. The powered flexion wrist which has a ½ inch threaded distal end was connected to the humeral section via the delrin wrist unit. A forearm was 3D printed and fastened to the articulating end of the powered flexion wrist. At the most distal end of the forearm, an Ottobock pediatric myoelectric wrist unit was epoxied to the forearm and the Ottobock Myolino hand was connected as the terminal device. The device was wired with a single site electrode, batteries and touch pad which would act as a switch (Figure 4). The electrode was placed at the patient's proximal pectoralis major. The switch was to be routed to the right side of her collar bone so that it could be accessed by her chin without interfering with the pectorals muscle movement.

Figure 3: myoelectric prosthesis

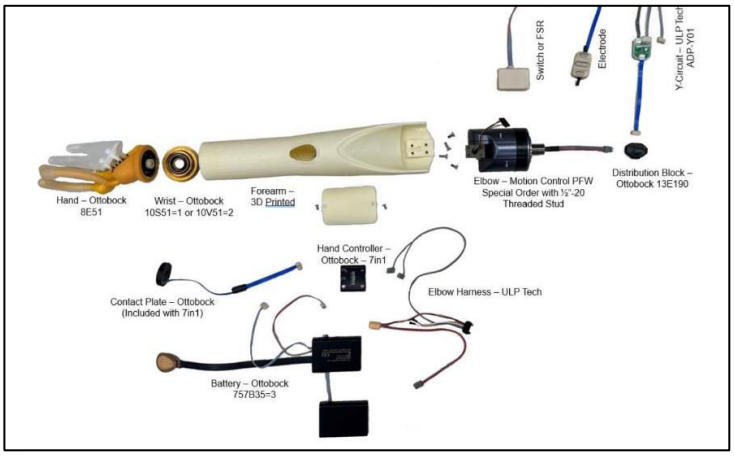

Figure 4: Components used in the myoelectric prosthesis

The patient was fit with the myoelectric prosthesis and operated it well. For simplicity and to prevent frustration, the integration of elbow function was initially deferred to later date to allow the patient to adapt to one component at a time.

The myoelectric prosthesis provided several opportunities that the body powered device could not offer for this specific patient presentation. First, it enabled the patient to operate the terminal device with very little force, excursion, and energy expenditure in comparison to the body powered cable devices. Second, she had the opportunity to flex the arm at the elbow which did not require any further force or excursion than what she was already using to control the terminal device. This allows for opportunities such as feeding herself, playing with toys in multiple dimensions, carrying objects, lifting them up to shoulder height and putting them as low as waist hight (Figure 5). All of this can now be done without gross movement of her spine and scapular deviation. It also reduces the amount of time that she must use her toes, foot, ankle, knee, and hip to bring something from the ground to the upper half of her body. The myoelectric system will also reduce the stress on her spine of having to be a flexed position as she would be able to maintain her posture while using prosthetic arms compared to the body powered prostheses and compared to using her feet.

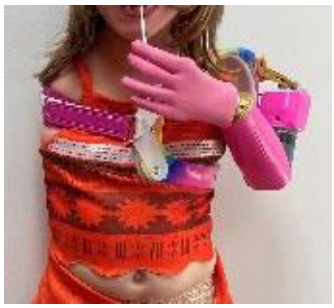

Figure 5: powered prosthesis in use

ADDITIONAL OBSERVATIONS

The patient displayed right foot dominant. With the provision of the more functional prosthesis, we observed that she was able to use her prosthesis during bilateral engagement with her right foot. Fabricating a left upper extremity prosthesis allowed for her to use her right dominant foot to pass things from her foot to the hand of the prosthesis (Figure 6). A bilateral set of powered prostheses would have been both heavy and bulky and may have limited this functional capacity. The unilateral fitting allowed for open space and freedom to move enabled her to use her feet.

Figure 6: bilateral engagement of the prosthesis

CONCLUSION

The current options for pediatric components are limited. Additive manufacturing and creative repurposing of existing components represent alternate pathways to facilitate functional solutions within this small patient population. In the case of bilateral limb deficiency, consideration should be given to preserving existing function with any attempts towards prosthetic care.

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"*Written informed consent was obtained from the patient's guardian prior to the introduction of all non-commercial prosthetics components.*"

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