CASE STUDIES: FITTING PATIENTS WITH HEAVY DUTY BI-DIRECTIONAL RATCHETING THUMB RAIL PROSTHESIS FOR CARPOMETACARPAL AMPUTATIONS

[1]Ben Pulver, MS, [2]Kyle Sherk, MS, CPO, FAAOP, [2]Daniel Hill, MSPO, CP, [1]Serena Kishek, [1,3]Stephen Huddle, MS, [1,3]Richard Weir, PhD, [1,4]Jacob Segil, PhD, [1]Levin Sliker, PhD

[1]Point Designs

[2]Hanger Clinics

[3]University of Colorado Denver | Anschutz Medical Campus

[4]University of Colorado Boulder

ABSTRACT

The loss of the thumb from the hand is a debilitating injury representing a 40% impairment to the hand. The replacement of the function of the thumb is a challenging engineering problem for prosthetic device designers due to the numerous degrees of freedom of the thumb. Most commercially available prosthetic devices for thumb amputations do not provide for adduction or rotation of the thumb. Here, we describe the design of a modular locking adduction rail for people with thumb loss proximal to the metacarpophalangeal joint. This device is compatible with the commercially available Point Thumb prosthetic thumb from Point Designs and allows users to move the prosthetic thumb from a flat hand position to an oppositional position. The design of the bi-directional adduction rail is briefly detailed. Then, two case studies are presented which detail the clinical implementation of the adduction rail into a partial hand prosthetic socket for two different patients. These are some of first trial fittings of the adduction rail system and demonstrate significant functional gains achieved with this novel device.

INTRODUCTION

Partial hand amputation is 10 times more common than all other categories of upper limb amputation combined [1]. These amputations can be a severe disability, especially if the amputation involves the thumb and/or multiple digits. Upper limb amputation can cause physical, psychosocial, and economic damage to an individual and can lead to depression, anxiety, loss of self-esteem, and social isolation [2], [3]. Fewer than half of partial hand amputees are able to return to the same job after amputation and most find that the prosthetic devices are insufficient to meet the demands of their work [4].

The loss of the thumb presents a particularly challenging type of partial hand amputation. The thumb is an essential digit in the formation of grasps and production of appropriate grip strengths for activities of daily living [5]. The loss of the thumb represents a 40% reduction in hand function [5]. The complexity of the thumb kinematics creates a challenge in the reproduction of the five degrees of freedom in a prosthetic device including three flexion, an adduction, and a rotation degree of freedom [6]. Flexion only makes up approximately 25% of the thumb's function [7]. Today, there are passive prosthetic thumbs (e.g. – TITAN Thumb, Partial Hand Solutions), body-powered thumbs (e.g. - ThumbDriver, Naked Prosthetic), and powered prosthetic thumbs (e.g. – iDigits, Ossur). In these cases, the prosthetic devices predominately recreate the flexion degrees of freedom of the thumb. In this work, we sought to design a bi-directional adduction rail which adds two additional degrees of freedom to the commercially available Point Thumb.

Table 1 compares the different prosthetic options available. Impairment values are calculated using the American Medical Association (AMA) guide for evaluating upper extremity impairment [7]. This comparison does not factor in issues like loss of sensation, device durability, and device ease of use, all of which have a significant role in device adoption and retention. Application of the Point Thumb and adduction rail system provides the largest range of motion and most functional benefit.

Table 1: Digit and hand impairment remaining after fitting of a thumb prosthesis.

Prosthesis	Examples	Impairment*	
		Digit	Hand
No Device	---	100%	40%
Static Opposition Post	livingskin™	55%	22%
MP Flexion	TITAN Thumb	37%	15%
MP and IP Flexion	Point Thumb	31%	12%

MP Flexion and Radial Abduction	VINCENTpartial passive	27%	11%
MP Flexion and Adduction	i-Digits Access[1] VINCENTpartial active[2]	17%	7%
MP Flexion, IP Flexion, and Adduction	Point Thumb with Adduction Rail[1] prototype	10%	4%

[1]Adduction is passive, [2]Adduction is active
**Does not include impairment due to lack of sensory information*

ADDUCTION RAIL DESIGN

The adduction rail presents a novel method to translate the thumb between a hand open position to an opposed adducted position. The adduction rail entails a curved, toothed track that serves as the interface between the prosthetic socket and the thumb carriage. The curve of the track enables the center of rotation of the adduction motion to be located virtually inside the residual limb thus reducing the total size of the prosthesis. The ratchet teeth on the track enable a similar locking mechanism as found in the Point Thumb and other mechanical digits offered by Point Designs. The carriage rides along the track and houses the pawls which engage the ratcheting teeth and thereby locks the carriage in an adducted position. Two levers enable the user to lock/unlock the pawls and translate the carriage along the track in a bi-directional manner. This dual pawl-lever system enables the ratchet to function in two directions unlike a traditional ratchet. A shell covers the carriage and provides a rotational degree of freedom between the thumb and carriage using a spring-loaded toothed mechanical interface. All features of the bi-directional adduction rail can be manipulated in a unilateral fashion. Finally, a variety of shell designs enables the fixturing of different prosthetic thumb options onto the adduction rail.

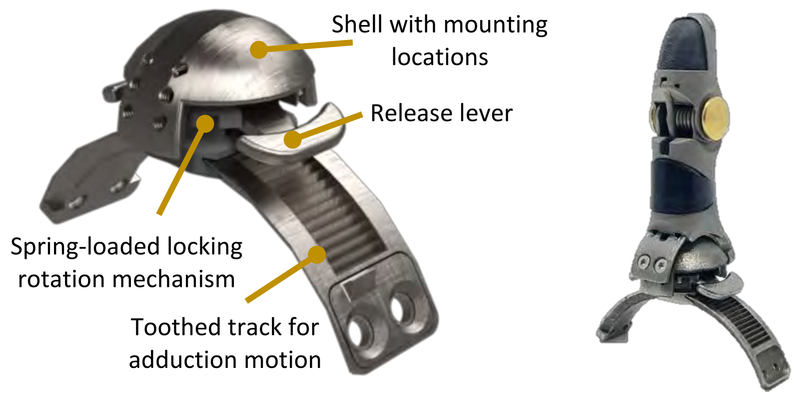

Figure 2: (Left) Rendering of adduction rail prototype with design features highlighted. (Right) Physical adduction rail prototype with Point Thumb attached.

Initial prototypes of the adduction rail were produced using metal laser sintering additive manufacturing techniques. The use of additive manufacturing methods enables the creation of internal mechanisms and unique toothed profiles which are used throughout the adduction rail. Hand tools were used to post-process the printed components which were then assembled into functional prototypes using other off-the-shelf springs and fasteners. Prototypes were provided to collaborating clinicians in order to conduct initial case studies of the Point Thumb and adduction rail.

CASE STUDY 1

Presentation - The subject is a 61-year-old right hand dominant male. He owns and works in an industrial metal shop. His left thumb was amputated at the carpometacarpal (CMC) joint due to trauma in 2002. He has not used a prosthesis before, due to limited device designs for his level of amputation and has adapted well to life without his left thumb. He reports only having issues with controlling two-handed tools and playing guitar. He desires a heavy-duty thumb component for his work environment and to reduce the over-use syndrome he has begun to experience in his right hand/arm.

Treatment – The patient was fit with a partial hand socket, a static Point Design thumb, and the adduction rail prototype (see Figure 3). He was immediately impressed with his ability to hold large objects (tube of cleaning wipes and a tissue box). Smaller objects were a bit more troublesome to grasp (screwdriver handle and a screw). The patient was able to use the device for at least three weeks both at work and at home.

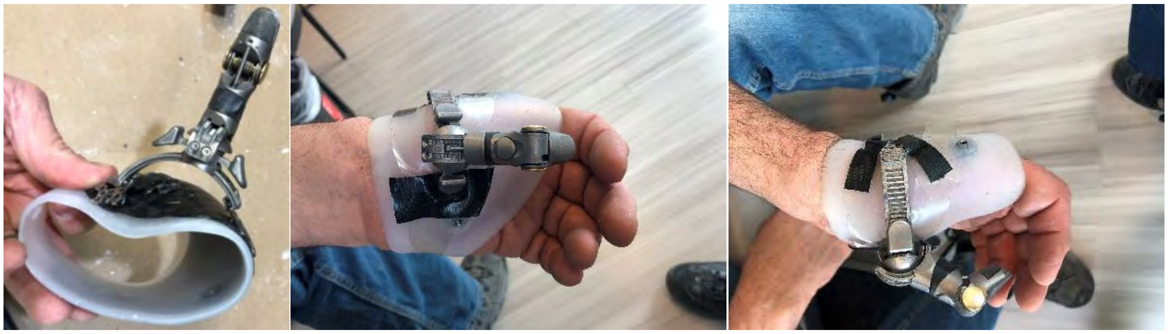

Figure 3: The adduction rail prototype and Point Thumb mounted to the partial hand socket.

Outcome – Patient reported, remotely, that he has liked the thumb but has not been able to get to the office for in-person follow-up due to illness in the family. Additional follow-up for this patient will be conducted in the coming months to collect more feedback and some outcome measures. As seen in Figure 3, one of the challenges with this fitting was the patient's presentation and the fitting of the adduction rail track close to the residuum. This issue was addressed in the next iteration of the device that was used in the case study in the following section and the fitting was significantly improved.

CASE STUDY 2

Presentation – The patient is a 45-year-old female who sustained a workplace injury in 2010 resulting in the amputation of her left thumb at the carpometacarpal (CMC) joint. The injury also resulted in a long transradial amputation of her right hand. At the time of the evaluation, the patient reported using various transradial prostheses but had not received a prosthesis for the left thumb. Prior to the accident she was right-handed but has since relied heavily on her left hand for activities of daily living. Her left hand became the dominant side, capable of hook and cylindrical grasp paired with extreme wrist flexion and fine motor grasp between index and middle digits via MCP adduction. She is the primary caretaker of her home, performing most of the upkeep, including: lawn care, gardening, caring for chickens and large dogs, cooking, sweeping, dusting, shopping, etc. She has resorted to compensatory strategies and modified tools to continue performing as many of her ADL's as possible, but reported significant overuse symptoms and a heavy reliance on others for assistance.

Treatment – Due to the variability of the patient's daily tasks, a passively positionable thumb and novel adduction rail were recommended to improve her grasp security with delicate objects, as well as heavy duty – outdoor activities. The adduction rail prototype would allow her to manually maneuver the thumb in various opposed and non-opposed positions. The patient was fit with a trial prosthesis that included a custom high temperature vulcanized (HTV) silicone socket with a vivak frame. The adduction rail prototype and Point Thumb were mounted on the frame and aligned in a manner that gave the patient access to as many grasp patterns as possible.

Figure 4: Patient demonstrating the ability to achieve a variety of oppositional grasps to hold various objects as well as a flat hand posture to maximize use of the intact digits.

Outcome – The patient immediately saw functional benefit of the prosthesis in the clinic. She demonstrated the ability to position the thumb and rail with both her right transradial prosthesis and distal end of her residual limb. The patient used the prosthesis for approximately 3 weeks. She reported using the prosthesis 3-5 hours at a time, with the longest duration being 8 hours. She found it to be most useful in carrying heavy items such as buckets of water, chicken feed, and dog bowls. Inside the home she found immediate benefit when holding anything with a handle, including brooms, vacuum cleaners, pots, pans, duster, paint brush, and a paint roller. She reported significant benefit in having the ability to modify the adduction angle to best position the thumb according to the object being grasped. Due to her being so well adapted to using her remaining digits for fine motor tasks, she appreciated the ability to move the thumb to a non-opposed position so it would not interfere, especially when typing and using a computer mouse. A definitive prosthesis will be provided and continued follow up including outcome measures are planned.

CONCLUSION

Thumb amputations, particularly at the CMC joint, present a variety of complicated functional, psychological, and occupational challenges. Restoration of the adduction and rotational degrees of freedom of the thumb is important for facilitating most grasps used in performing ADLs. The prototype adduction rail system presented here, in combination with the Point Thumb, allows for a robust thumb prosthesis that provides for flexion, extension, adduction, and rotation of the thumb. The two case studies presented here illustrate the need for such a device in that a traditional statically mounted thumb would limit the patient's ability to perform a number of key functional grasps. In both cases, use of the adduction rail and Point Thumb allowed patients to achieve their functional goals, ranging from metal work to caretaking activities. These positive early trial fittings indicate that the adduction rail system provides significant benefits to patients with CMC level amputations.

REFERENCES

[1] E. National Academies of Sciences and Medicine, *The Promise of Assistive Technology to Enhance Activity and Work Participation*. Washington, DC: The National Academies Press, 2017. doi: 10.17226/24740.

[2] D. Desmond and M. MacLachlan, "Psychological issues in prosthetic and orthotic practice: A 25 year review of psychology in Prosthetics and Orthotics International," *Prosthet Orthot Int*, vol. 26, no. 3, pp. 182–188, Dec. 2002, doi: 10.1080/03093640208726646.

[3] C. M. Parkes, "Psycho-social Transitions: Comparison between Reactions to Loss of a Limb and Loss of a Spouse," *British Journal of Psychiatry*, vol. 127, no. 3, pp. 204–210, 1975, doi: 10.1192/bjp.127.3.204.

[4] H. Burger, T. Maver, and Č. Marinček, "Partial hand amputation and work," *Disability and Rehabilitation*, vol. 29, no. 17, pp. 1317–1321, Jan. 2007, doi: 10.1080/09638280701320763.

[5] Z. Kuret, H. Burger, and G. Vidmar, "Influence of finger amputation on grip strength and objectively measured hand function: a descriptive cross-sectional study," *International Journal of Rehabilitation Research*, vol. 38, no. 2, pp. 181–188, 2015.

[6] L. Y. Chang and Y. Matsuoka, "A kinematic thumb model for the ACT hand," in *Robotics and Automation, 2006. ICRA 2006. Proceedings 2006 IEEE International Conference on*, 2006, pp. 1000–1005.

[7] G. Andersson and L. Cocchiarella, *AMA Guides® to the Evaluation of Permanent Impairment*, 5th ed.

[8] A. M. Dollar, "Classifying Human Hand Use and the Activities of Daily Living," in *The Human Hand as an Inspiration for Robot Hand Development*, R. Balasubramanian and V. J. Santos, Eds. Cham: Springer International Publishing, 2014, pp. 201–216. doi: 10.1007/978-3-319-03017-3_10.