ENHANCING UPPER LIMB PROSTHETIC FABRICATION WITH 3D PRINTING TECHNOLOGY: OPPORTUNITIES AND APPLICATIONS

Daniel DaFonseca RTP, Heather Daley, CP, Wendy Hill, OT

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

ABSTRACT

This study explores the transformative impact of 3D printing technology in the field of upper limb prosthetics, highlighting its pivotal role in customizing prosthetic devices to meet individual needs with precision and efficiency. Through detailed examination of practical applications ranging from musical playing devices to recreational implementation, we showcase the versatility of additive manufacturing in enhancing patient outcomes. Despite potential hurdles such as cost and the necessity for specialized expertise, the evidence underscores the substantial benefits of 3D printing, including significant improvements in prosthetic functionality, patient satisfaction, and overall efficiency and effectiveness. Our findings advocate for the integration of 3D printing into prosthetic fabrication, emphasizing its potential to revolutionize patient care by offering tailored solutions that cater to the unique requirements of individuals with upper limb differences.

INTRODUCTION

3D printing is a remarkably valuable tool for fabrication of upper limb prosthetic devices that is under-utilized in many areas. 3D printing is not as media tends to stereotype it as, an enormous cost saving, plug and play solution to the entire cost and process of prosthetic production. The material and fabrication cost of an upper limb prosthesis is just a fraction of the entire cost of a fitting [1]. Replacing this with additive manufacturing (AM) makes very little difference in this front, and if anything, it can increase costs as it requires specialized knowledge to utilize it at all.

The benefits of AM are substantial and include more accurate, repeatable, and higher quality end results, or devices that aren't possible with traditional fabrication methods [2], [3]. Time savings are also a benefit in many cases, where after a design is finished, the operator can work on something else while the product is being printed. Less waste is generated with AM and is less labour intensive in the long term [2], [4]. AM has the potential to be the means for many end use applications in the industry today, depending on the type of technology in question. Suitable methods for use in prosthetics include technologies such as selective laser sintering (SLS) nylon parts or multi jet fusion (MJF), selective laser melting (SLM) for metal parts as well as direct metal laser sintering (DMLS). Less suitable technologies for most end use parts really narrows down to the most accessible one, fused deposition modelling (FDM). This is the most commonly used form of 3D printing portrayed by the media for prosthetic arms, and people often are misled into thinking a functional prosthesis can be fabricated for just $50 with a printer that costs less than $1000[5] . Considering that FDM printing is essentially a smart hot glue gun that relies on interlayer adhesion for structural integrity, regardless of material properties, this makes this application not suitable for truly robust end use applications. FDM is more suitable for rapid prototyping, fabrication aids, dynamic alignment fixtures, and numerous unique uses that will be outlined as examples in this paper. Ultimately, since AM is typically not intended for high-volume production, but very complex and custom small production, it is ideally suited for this industry.

CASE EXAMPLES

The following cases (of which informed consent was obtained under the guidelines and approval of UNB's research ethics board prior to the study) demonstrate the value of 3D printing in an upper limb prosthetic clinic:

Case 1

<u>Presentation</u>

MS is a 37-year-old male who sustained a workplace injury in 2010 resulting in a transhumeral amputation of his right arm. He had been an avid musician and was previously in a band as a guitarist before his accident. Since his amputation and prosthetic fitting, he has returned to work in a steel plant and has resumed many of his previous hobbies, including playing bass one-handed with the tapping technique as his fretting hand. He was hesitant to try any other stringed instrument as he did not want to learn to play in an adapted way. However recently, he inquired about the possibility of strumming a guitar again.

<u>Treatment</u>

After much discussion about positioning and breaking down the skills required for strumming a prototype guitar playing device was designed using FDM ABS, and the final versions were manufactured from FDM PA12 CF, and SLS Nylon12, and utilizing a pin lock liner for suspension. For the diagnostic phase, a 3D printed socket was made with a ball socket distal arm to determine the best strumming position with a wide range of adjustability. Once that was determined, a fine adjustment version was made with a solid arm piece in the ideal strumming position and a TRS guitar pic holder at the terminal end to allow for minor tweaks in pick position. This socket was made as a topology optimized design in order to reduce as much weight as possible while still maintaining adequate strength and stiffness.

<u>Outcome</u>

The outcome from this fitting was a very lightweight but durable device that the patient was very happy to use. He initially found it awkward to strum using shoulder movement rather than his wrist and hand but felt that with practice he would improve. He felt a smaller guitar would improve his positioning and give him better control of his strumming, so we took the trial device to a local music shop to try various sized guitars. See photos. He was able to trial multiple guitars for shape, size and sound which helped us fine-tune the positioning of the terminal device in the final design. After using it at home for several weeks, the patient reported that with extended playing times, he was initially experiencing soreness in his shoulder, though with more practice and repetition and rest, this problem has lessened. Additionally, a softer custom pick was requested and then fabricated from thermolyn to mitigate the aggressiveness of less accurate strumming.

Figure 1: custom transhumeral guitar device

Case 2

<u>Presentation</u>

NR is a 6-year-old girl who was born with a transmetacarpal limb difference on her left side. She has equal length arms to the wrist level and full range of motion in her wrist. She is able to complete most of her daily activities independently with no prosthesis but has requested an adaptation for several recreational activities such as riding her bike, holding a skipping rope, and most recently, swimming. She was starting swimming lessons, and her mom was concerned that she would not be able to swim laps in a straight line because of her smaller hand span in the water.

<u>Treatment</u>

We initially looked at commercial swim paddle products geared to swim training but could not find a suitable product to fit her small size or that could easily be adapted to remain secure on her hand in the water. Ultimately, we decided a 3D printed custom device with a pocket for her hand would be the best solution. A scan was taken of her hand and forearm and the swim paddle prototype was then printed with FDM PETG. PETG was the filament of choice as it is chemical and UV resistant with a higher heat deflection temperature than other materials. This made it suitable for swimming pool and outdoor settings. With inspiration from commercial swim paddles, the design incorporated s perforations to allow water to move through it and not give complete resistance. The suspension was achieved with a 15-shore silicone strap made from a 3D printed mould that has notches to adjust tightness.

Outcome

The outcome from this device was well received by NR. She found it comfortable, it helped her with swimming symmetry during swimming lessons, and she was very proud to show off her special swim mitt in her favourite colour.

Figure 2: custom partial hand swim paddle

Case 3

Presentation

CG is a 39-year-old female with a left-sided congenital limb difference at the wrist level. She wears a passive prosthesis daily, mainly for aesthetics. She is independent in all of her daily activities, however she mentioned at a recent appointment that she was having trouble holding a drumstick when playing the drums at home. She is very musical and had adapted her method of playing many instruments, but the tape she was using to help hold the drumstick in place on her residual limb was causing some discomfort and skin irritation.

Treatment

CG asked if we could fabricate a simple device that could help hold the drumstick more securely but that would still give her some control over the rhythm while drumming. She did not want to wear a hard socket to accomplish this. We discussed positioning of the drumstick on her limb and options for materials. A trial device made with FDM TPU. With a long residual limb, this allowed for an abundance of surface area to work with for force distribution. . The device is a single piece flexible TPU print with an integrated lacing for a boa system to adjust tightness. The drumstick is friction fit into two sleeves that are 10% infilled to reduce rigidity to give a more natural hit and rebound on strikes.

Outcome

The outcome from this trial device was great. The patient was happy with the fit and comfort in the new device and has been able to continue playing drums more often and for longer sessions with improved comfort and control.

Figure 3: custom wrist disarticulation drumstick holder

DISCUSSION

These are just a handful of examples of AM use in an upper limb prosthetic clinic setting., AM is also a useful tool for creating full sockets, forearm shells, cosmetic covers, tools, foundations for lamination, adapters, moulds and so on. Looking forward, there is a potential to further explore fully 3D printed prostheses with SLS or MJF Nylon, custom printed metal terminal devices (TDs) with SLM/DLMS metal printing, and 3D printed silicone sockets and liners. While there are many benefits to these applications, cost savings is not the primary objective. The benefits of 3D printing in prosthetic clinic include material selections, material combinations, weight reduction by material choice and/or design, and aesthetics.

CONCLUSION

The exploration of 3D printing in upper limb prosthetic clinics reveals a landscape brimming with opportunities yet marred by underutilization. This paper demonstrates the transformative potential of additive manufacturing in enhancing prosthetic design, customization, and functionality, while also addressing the challenges of cost and requisite specialized knowledge. The case examples provided showcase the technology's capability to produce outcomes previously unattainable through traditional methods, showcasing 3D printing's role in advancing patient-centric solutions and opening avenues for innovation in prosthetic care. As we navigate the evolving intersection of technology and healthcare, it is beneficial to further integrate 3D printing into prosthetic fabrication, leveraging its unique features to meet the complex needs of patients, thereby heralding a new era of personalized and accessible prosthetic solutions.

REFERENCES

[1] J. ten Kate, G. Smit, and P. Breedveld, “3D-printed upper limb prostheses: a review,” *Disabil Rehabil Assist Technol*, vol. 12, no. 3, pp. 300–314, Apr. 2017, doi: 10.1080/17483107.2016.1253117.

[2] Baschuk CM, “Stakeholder perspectives 3D printing and the evolution of partial hand prostheses: my journey from theory to practice,” *Canadian Prosthetics & Orthotics Journal*, vol. 6, no. 2, 2023, doi: 10.33137/cpoj.v6i2.42139.

[3] K. F. Gretsch, H. D. Lather, K. V. Peddada, C. R. Deeken, L. B. Wall, and C. A. Goldfarb, “Development of novel 3D-printed robotic prosthetic for transradial amputees,” *Prosthet Orthot Int*, vol. 40, no. 3, pp. 400–403, Jun. 2016, doi: 10.1177/0309364615579317.

[4] A. Manero *et al.*, “Implementation of 3D Printing Technology in the Field of Prosthetics: Past, Present, and Future,” *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 1641*, vol. 16, no. 9, p. 1641, May 2019, doi: 10.3390/IJERPH16091641.

[5] “The Synergistic Potential of Embracing 3D Printing in O&P.” Accessed: Mar. 06, 2024. [Online]. Available: https://www.linkedin.com/pulse/synergistic-potential-embracing-3d-printing-op-chris-baschuk/?trackingId=7Bf1k07eQxWDnUdTvr%2Fa1A%3D%3D