ARRIVET

DEVELOPING ATHLETIC PROSTHETICS VIA 3D PRINTING

Richard Burman[1], **Misha Handman**[2]
Camosun College[1,2]
Email: burmanR@camosun.ca[1]*; handmanm@camosun.ca*[2]

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ABSTRACT:
Prosthetic limbs present a highly unique research challenge, requiring intense customization for optimal use cases. These challenges are heightened for athletes, who engage with their prosthetics in highly competitive environments, placing them under tremendous stress. Thomas Normandeau, a champion Para Athlete, approached Camosun Innovates to develop such a prosthetic, able to aid him in his training regimens and reduce the risk of injury. Camosun Innovates undertook a human-centered design approach that foregrounded Normandeau's needs and observations. Through a mixture of digital scanning and 3D-printed parts constructed using Nylon 12, a unique carbon-reinforced nylon traditionally used in the aerospace and automotive industries, the Camosun team was able to rapidly iterate a customized, properly fitted prosthetic with unique, lightweight joint pieces precisely calibrated to Normandeau's arm length, and without sacrificing the prosthetic's ability to hold up under tension. The success of this prototype holds potential for other prosthetics both within and without the athletic sphere, with the potential to help users with exercise routines and common lifting and carrying tasks, from grocery shopping to household chores.

Keywords: 3D Printing; prosthetics; nylon 12

1. RESEARCH CHALLENGE

Located in Victoria, British Columbia and serving from the traditional, unceded territories of the Lekwungen and W̱SÁNEĆ peoples, Camosun College is one of more than 100 colleges supporting students and communities across Canada. Camosun has been at the forefront of student learning and training for Greater Victoria for over 50 years, with more than 160 programs serving over 14,000 students; its educational profile features a key commitment to applied learning, especially applied research. Within the College is Camosun Innovates (CI), which supports college applied research, business development, and services for industries ranging from manufacturing and agriculture to sports and the arts. CI works with almost 100 industry partners each year to develop unique applied research solutions to pressing problems, without retaining intellectual property rights or competing with small and medium-size enterprises (SMEs). Its engineers and technologists collaborate with local and regional businesses through a combination of government investment, local outreach, and private grants from innovation-focused not-for-profit organizations, while supporting students through capstone courses and term work on industry projects, frequently leading to regional job placement for recent graduates.

Athletics Canada is the governing body for Canadian track and field, para-athletics, cross-country running and road running sports. A charitable organization, Athletics Canada supports high-performance athletes in national and international events, and provides leadership in Canadian developmental athletics. In 2021, Athletics Canada approached Camosun Innovates with the goal of developing a new training prosthetic for Canadian Para athlete Thomas Normandeau, the Canadian record-holder for the T47 400-meter race and finalist at the 2019 IPC World Championships and Parapan American Games. Born without a left hand, Normandeau wanted a top-quality lifting prosthetic to support weight and resistance training as part of his training regimen. The prosthetic was required under a tight timeline in order to allow Normandeau train to his full potential in time for the next round of competitions.

Typical weightlifting prosthetics are designed with two parts: a sleeve, custom-shaped to the athlete's limb, and an end-effector (also known as the 'grip') designed to clamp onto a handle or bar (see Fig 1). Unfortunately, commercially available grips all have significant drawbacks related to size and weight which renders them inefficient or even unusable for athletes such as Normandeau. Off-the-shelf grips are heavy, which creates a weight imbalance with an athlete's other limb; this problem was exasperated by the types of ballistic movement that Normandeau was engaging in. In addition, the length of Normandeau's limb meant that there was insufficient space to mount an off-the-shelf grip and still maintain symmetry between his left and right forearm. Symmetry in exercise is critical for resistance training, and a lack of symmetry in an explosive sport like sprinting reduces an athlete's top speed and frequently results in injuries.

Figure 2: End Effector Hook.

In addition to the immediate difficulties with commercial models, Normandeau's desired exercise routine required a variety of different end-effectors customized to individual training tasks. A single grip could not accomplish this goal, leaving him with a less varied and effective regimen. He came to Camosun Innovates in search of solutions to these challenges. With no specific standards for a training-focused prosthesis, due to the individual requirements and capabilities of athletes, the goal for the design was to make something that was comfortable, safe to use, and functional - easily used and adaptable to multiple exercises.

2. METHODS

The Camosun team undertook the challenge with a human-centered design approach that foregrounded Normandeau's needs and priorities. This process began with developing a digital scan of Normandeau's arm. Getting the most accurate scan possible involved a mixture of high-tech and low-tech solutions. Normandeau's arm was wrapped in saran wrap, compressing the tissue in much the same way that a prosthetic would before digital scanning took place, and creating a custom fit that dispersed the pressure through Thomas's limb. An Artec Eva white-light scanner was chosen to scan the arm, as the scanner was able to acquire data rapidly while Normandeau stood still. With the initial scan complete, the team created a form-fitting prosthetic with an adjustable "hook". With this intermediary prosthetic, the team positioned Normandeau in athletic stances and adjusted the grip to ensure symmetry in length and angle relative to the forearm.

The next step in the process was the investigation of potential methods that could be used to manufacture a grip that was cost-effective, lightweight, resilient enough to withstand training, and durable enough not to need frequent replacement. Camosun initially looked into the possibility of using a traditional approach with CNC machined aluminum parts, but this would result in a heavy part with a relatively high cost of manufacturing. This led researchers to consider 3D printing; the use of 3D-printed parts is ideal in the rapid, iterative processes employed in human-centered design approaches, and Camosun believed that this would also be true for prosthetics.

Nylon 12, a unique carbon-reinforced nylon available from Stratasys, offered exactly what Camosun was looking for. Traditionally used in the aerospace and automotive industries and to produce custom home appliance parts, Nylon 12 is notable for its fatigue, chemical, and temperature resistance. Each layer of this lightweight material bonds well with the layers above and below as it is printed, protecting against breakage, and with an Unnotched Izod Impact rate of 1,656 J/m, the material is particularly resistant to the sorts of sudden impacts and repetitive strains that resistance and weight training are likely to place on a prosthetic. Having selected this material and manufacturing method, the grip was specifically designed for 3D printing with a geometry that was optimized for the forces that were likely to be generated by Thomas.

Because 3D printed parts are weakest in tension applied perpendicular to the build layers, the orientation of the build layers was of particular importance and consideration during this process. The prosthetic was expected to experience its maximum tensile stress during deadlift exercises; highly trained explosive male athletes can generate forces up to three times their body weight during such maneuvers. Assuming a body mass of 85 kilograms, this corresponds to an approximate tensile force of 2500 Newtons on the prosthetic. To ensure the utmost safety for the user, the prosthetic needed to consistently withstands a tensile force of twice that amount, 5000 Newtons. To achieve this, an analysis was conducted to identify the weakest areas of the prosthetic, specifically those with the smallest cross-sectional area that must resist the tensile load. After a few iterations, 3D-printed samples of these critical areas were successfully tested under a cycled load of 5000 Newton force, exceeding the expected load by a factor of 4.

With the design for a compact and lightweight grip complete, the Camosun team turned their attention to the creation of a custom sleeve that would support the grip. These sleeves are commonly made using composites. While these composite parts meet the requirement of being lightweight and durable, they are expensive to manufacture as they require the creation of a mold. In addition, any changes to the fit requires modifications to the mold and the creation of a new part, thus a significant cost and complexity. As the grip was already being 3D printed, the engineering team made the decision to utilize the same manufacturing method for the sleeve. By 3D printing key parts of the prosthetic in Nylon 12, the Camosun team was able to create unique, lightweight joint pieces without sacrificing the prosthetic's ability to hold up under tension. In addition, through a rapid, iterative process, they relaxed the fit in areas where tissues over bony prominences may be compromised.

With the prototype complete, iterative applied testing of the prosthetic began. Normandeau tested the prototype in the gym, running it through extended exercise routines and documenting any instances of pain, discomfort, or skin irritation (see Fig 2). Based on the results, the team discovered that the prosthetic's strapping system needed to be adjusted to make it easier to both tighten and release the prosthetic with one hand; the result was the development of a closed-grip prosthetic which could be used by Normandeau without external assistance. Additional revisions were made to the fine details of the prosthetic based on Normandeau's feedback and observation; this not only improved the prosthetic's comfort, but also allowed the team to improve the prosthetic's range of motion and open up the possibility of adding new training exercises to the mix (see Fig 3).

Fig 2: Thomas Normandeau testing the prototype

Fig 3: The final delivered prosthetic

3. RESULTS

Thanks to the ease of iteration in 3D-printed designs, Camosun was able to improve the comfort of the prosthetic and adjust its gripping end to be removed and replaced according to the athlete's needs. This design process, facilitated through the use of 3D scanning and 3D printing technology, has removed design constraints and allowed the team to develop an incredibly flexible prosthetic system that Normandeau continues to rely on in his daily training.

To expand the range of exercise that can be performed using the lifting prosthetic, additional end-effectors which can be quickly changed during an exercise session, were created for Normandeau at his request. The first of these is a "hook" that can be used where a closed grip is not required. This hook facilitates ease of use as the grip can be used to grasp or release from a bar, handle, or tubing. The second end effector is a "paddle" that allows Normandeau to perform dynamic exercises with medicine balls (see Fig 4). At Normandeau's request, the Camosun team is currently exploring the development of a third end effector, which will be used during races as both a starting block for Normandeau to lean on at the beginning of a race, and to provide weight symmetry to improve his speed and reduce the chances of injury due to an unbalanced frame, a common concern for champion Para athletes. Camosun is now looking forward to cheering Normandeau on when he competes at the World Para Athletics Championships in Paris, taking place in July 2023.

Fig 4: Normandeau training using the paddle end effector.

4. POTENTIAL APPLICATIONS

The success of Normandeau's prosthetic has allowed Camosun Innovates to apply the lessons learned in its creation to other fields of sport. In particular, the human-centered design process that developed this prosthetic has been applied to the field of Para Hockey, developing customized sleds for athletes that protect their limbs from potential injuries during play, dramatically improve athlete comfort both in training and on the ice, and even provide improved performance. In part due to the capabilities provided by these assistive devices, the Canadian Para hockey team placed silver at the 2023 World Para Hockey Championship.

3D-printed prosthetics based on Camosun's initial design also hold tremendous potential outside of athletic pursuits, with the potential to help users with exercise routines and common lifting and carrying tasks, from grocery shopping to household chores. Many people with disabilities take advantage of custom-made assistive devices, often created for specific needs and purposes. These devices cannot be mass-produced due to the differences in individual capabilities and body frames, and 3D printing the parts will allow for the initial development of these devices for specific purposes, followed by inexpensive custom development for individual use.

In addition to specific task-oriented prosthetics and end effectors, the design process used to develop Normandeau's prosthetic also holds potential for general prosthetic creation. Camosun Innovates is currently in talks with a regional prosthetist who is adapting our work to create a new scanning model, which incorporates a mixture of traditional mold-casting and iterative scanning design to develop durable, inexpensive prosthetics for daily use. Camosun Innovates is proud to be furthering access to customized prosthetics at an affordable cost, and excited to explore where this technology will lead.

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