Adapting Isokinetic Dynamometry for Individuals with Transtibial Amputations

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Abstract— **Transtibial amputations impact one's ability to perform activities of daily living. Continuous load bearing on the intact limb during ambulation and standing can lead to strength asymmetries in the lower limbs. Objective assessment of strength asymmetries in lower extremity muscles is critical as transtibial amputees are prone to several secondary conditions stemming from these musculoskeletal imbalances. Isokinetic dynamometry has been used to safely evaluate muscle asymmetries, but testing is usually performed using the participant's own prosthesis which can vary in available range of motion and suspension method. Furthermore, this methodology excludes those who are not prosthesis users. The purpose of this research was to design, build and test a transtibial adapter for dynamometry that can be used on the residual limb with or without a prosthesis for objective assessment of leg strength. Clinical feedback was sought from one transtibial amputee regarding the usability and comfort of the adapter while performing an isokinetic knee extension/flexion task. The participant was capable of completing the knee contractions without any reported pain or discomfort, suggesting that our prototype may be an option to adapt dynamometry for this population. Further research with the prototype with a larger sample and more contraction conditions is needed to further assess whether the design presented is a viable option to adapt dynamometry for transtibial amputees.**

Keywords— **transtibial, adapter, amputation, technology, design.**

I. Introduction

Limb loss affects the health and quality of life of many Canadians. More than 44,000 Canadians suffer from lower limb amputations [1]. Of these, more than 13,000 are transtibial amputations, making it the most common form of amputation in the country [1].

Transtibial amputations are associated with significant changes in body composition. A common compensation in this population is to increase weight bearing on the intact limb during walking and standing [2,3]. The higher weight bearing results in asymmetries in the lower limb musculature which often results in muscle weakness and muscle atrophy in the thigh and hamstring muscles of the affected leg [4,5,6]. These physiological changes can eventually lead to more debilitating secondary ongoing physical complications such as premature osteoarthritis and osteoporosis [7].

Due to their risk of developing secondary orthopedic complications, the rehabilitation and assessment of strength of the leg muscles in this population is important. One method of safely examining dynamic movements is the use of isokinetic dynamometers. These machines allow safe measurement of upper and lower extremity isokinetic movements at controlled angular velocities.These devices are popular in rehabilitative medicine are considered the gold standard for measuring joint torque output during dynamic contractions [8].

Individuals with transtibial amputations are usually excluded from the benefits of isokinetic dynamometry with respect to strength testing and and training due lack of accommodation of the ampuated limb. A few studies have tested prothesis users with dynamometry [5,9,10] however with challenges. The suspension methods of the prosthesis varies across indivdiuals and in some cases can restrict the range of motion of the knee. Currently, no commercially available isokinetic adapter is available for individuasl with lower limb amputations.

The purpose of this project was to design, build and test an adjustable adapter for individuals with transtibial amputations to safely and comfortably operate a dynamometer for objective strength measurement. The tool was developed to connect the user to the dynamometer to facilitate completion of knee flexion and extension either with or without a prosthesis. The prototype was built through a combination of aluminum machining and 3D printable parts.

There were three primary design requirements for the development of the transtibial adapter: 1) the adapter must be adjustable to the length and girth of the residual limb, 2) the adapter must allow the user to perform full flexion and extension of the knee, and 3) the adapter must be comfortable enough for the participant to exert maximal effort during dynamic movements against resistance during a testing session. Based on these requirements, a prototype adapter was built. These design requirements are discussed in the next section.

II. METHODS

A. General Design

The adapter consisted of two parts: a modular aluminum frame and a custom designed 3-D printed thermoplastic polyurethane cuff. The cuff was lined with a cushion to serve as the interface for force transmission between the user and the machine (Figure 1). The dimensions of the adapter were 55x30x20 cm. The cuff was designed in two parts: a front plate and a back plate. The parts were designed using a CAD software (Creo Parametric 5.0.0.0 by PTC®) and printed in a Raise 3D Pro2 (3D Technologies Inc.). All parts were custom machined in-house.

i) Adjustability of the prototype

To address the variability in residual limb length, the aluminum frame of the prototype was designed to allow the cuff to slide proximally or distally from the joint center. This was achieved by sliding the elongated aluminum extrusion directly on the Dynamometer (Figure 1). The height of the adapter was designed to range from 4 to 40 cm to account for the maximum and minimum limits of lower limb lengths across both sexes [11].

In order to accommodate adjustability to varying residual limb girths, the back plate of the adapter was designed with a hinge system that provides adjustability to any diameter of the lower leg (Figure 1). The diameter of cuff can range from 15 cm to 47cm, based on the average diameter for residual limbs in transtibial amputees [12]. The outside edge of the cuffs were designed with Velcro slots to allow for tightening of the adapter.

ii) Full range of motion (ROM)

An important feature of our design was the ability to allow for full ROM of knee extension and flexion. For this, the cuff was designed in two parts: a front plate which rested against the anterior face of the tibia, and a back plate which enclosed the posterior aspect of the calf musculature (Figure 1).

The front plate of the adapter was designed with a notch in the top lip to reduce pressure on the tibial tuberosity to prevent interference with the knee extension muscles (Figure 1). This notch allowed for a natural quadricep contraction with full extension ROM. The back plate was also designed with a concave edge in order to accommodate full knee flexion. Furthermore, the two-piece design of the cuff allowed for adjustability of the relative heights between the two pieces on the aluminum frame in order to address any knee joint anthropometric differences among users.

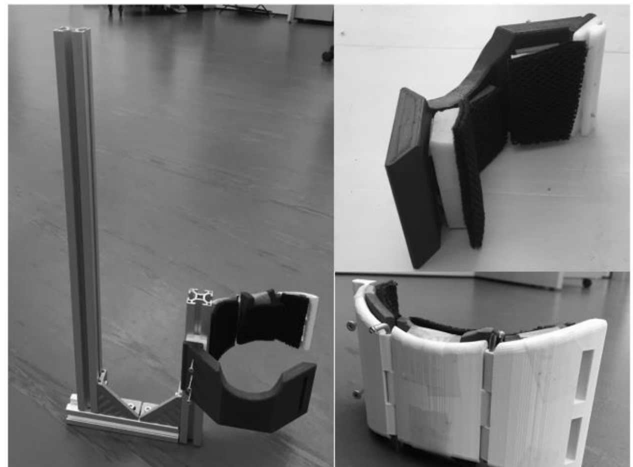

Figure 1. Prototype transtibial adaptor. Left shows the custom designed cuff mounted on the aluminum frame. Top-right shows front plate. Bottom-right shows adjustable back plate.

iii) User Comfort

The adapter was designed to be used during various contraction intensities for maximal dynamic strength testing. Therefore, reducing or even eliminating the discomfort and pain during force production is critical if accurate maximal values are to be recorded [12]. Furthermore, adequate padding and material were highly important as up to 24% of individuals with lower leg amputations report skin irritations and/or wounds due to prosthesis use [8]. For this purpose, a padded coating for the inside of the cuff was made of ethylene-vinyl acetate (EVA) to be able to evenly distribute the forces experienced by the user across the skin. To allow for breathability and reduced sweating, the inside padding was also lined with a layer of one-sided velour (ComforTex Air one-sided velour, Otto Bock Healthcare Canada Ltd, Ontario, CA).

B. User Testing and Clinical Feedback

To assess the first iteration of the prototype, one 59-year-old male prosthesis user (for 21 years) with a traumatic transtibial amputation (residual limb length =19 cm) performed maximal isokinetic knee contractions using the dynamometer. The participant was asked for their verbal feedback in relation to comfort, ability to perform the task and any further suggestions for the design.

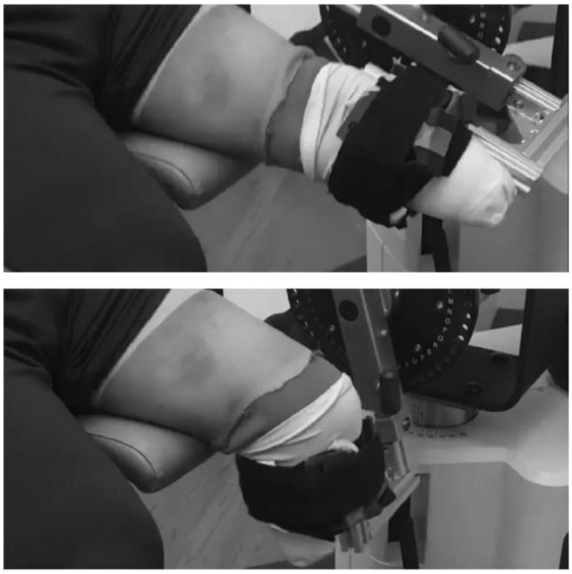

Figure 2. Adapter being used by an amputee in full extension (top) and flexion (bottom).

C. Instrumentation

The adapter was tested using Cybex HUMAC®/NORM^{TM} Testing and Rehabilitation System, model 770 (CSMI). All data were recorded at a sampling frequency of 100 Hz (with anti-aliasing filter at the front-end of the HUMAC interface with a cut-off frequency above 400 Hz) using an on-board analog to digital converter and associated computer software (HUMAC2009v10.00.

D. Experimental Protocol and Feedback

The participant was seated in an upright position on the Cybex dynamometer with his hips flexed at an angle of 90 °. Straps were fastened to stabilize his chest, thighs and hips. The adapter was then connected to the residual lower leg and adjusted for comfort. The isokinetic testing occurred between a position of maximum extension and a position of maximum flexion of the knee. Three practice contractions were allowed for the participant to familiarize with the protocol and ensure he understood the task and he experienced no discomfort while performing the contractions. The participant was asked to perform five consecutive isokinetic knee extensions and knee flexions at 60 °/s. The same isokinetic protocol was repeated with the intact limb. 5 minutes rest was allowed between the two tests. The standard isokinetic attachment for the dynamometer was used in the intact limb. After instructions were given, the participant was instructed to initiate the testing protocol at their leisure and torque data was recorded for 5 identical contractions at 60 °/s. The mean peak torque of the 5 consecutive contractions and set ROM were compared between the intact and the amputated limb using descriptive statistics. The participant was asked open-ended questions about any pain or discomfort felt throughout the experiment as well as their ability to perform each task maximally after the 5 repetitions.

III. Results

The participant was able to successfully complete both knee extensions and flexions through the full ROM as shown in figure two. The mean torque and the total ROM for both the intact and the amputated limb are provided (Table 1). Their feedback regarding the comfort and usability of the adapter was overall very positive and is discussed in the following section.

Table 1 Peak torque output in Nm and ROM in ° for 5 repetitions on the single participant at 60 °/s.

	Intact Limb		Amputated Limb	
	Mean	SD	Mean	SD
Extension	187.5	6.3	19.9	2.1
Flexion	52.3	8.7	8.7	2.2
ROM (°)	83		76	

IV. Discussion

This work presents a novel adapter to allow for the objective measure of strength in individuals with transtibial amputations to use isokinetic dynamometry. The design was tested in one isokinetic condition by a single participant with a unilateral transtibial amputation and verbal feedback about the comfort of the design was sought from them. The participant was able to complete the isokinetic protocol with no major discomfort. His feedback regarding the comfort and usability of the adapter was overall very positive.

It is difficult to compare if the results with previously published research which has shown a large variability in strength between the amputated and the intact limb [5,10,11]. A greater sample size may provide further insight. Furthermore, our prototype attaches to the limb at a more proximal point on the tibia than the previous studies therefore producing comparatively smaller torques due to the reduced moment arm. A direct comparison of the torque values might not be possible due to the differences in mechanical advantages. A future study could address this limitation by investigating the differences in torque output using our adapter against the traditional length using the prosthesis of the user.

The low variability between the extension and flexion across the five repetitions using the prototype adapter (extension =2.1Nm, flexion = 2.2 Nm) suggest that the device did not limit the ability of the participant to produce consistent torque outputs from contraction to contraction. In terms of ROM, the participant verbally reported that the prototype adapter allowed for a greater range of motion when compared to similar knee exercises performed with their prosthesis at the gym. This is in line with the similar ROM values extracted during the testing session between the intact and the amputated limb (Table 1).

Although this pilot work is promising, there is much work to be done. Only five repetitions at a single speed were tested with one participant in the present study. Expansion on this work should address different speeds, prolonged usage of the adapter and the usage of the adapter across different days to ensure comfort and reliability of force production.

In terms of the design, the adapter was able to successfully adjust to the size of the participants residual limb. The hinge mechanism chosen here is a viable design choice to attain the anthropometric universality desired. Further testing should be completed on people with different leg anthropometrics in order to assess if its design is truly able to accommodate for legs of different measurements. Nevertheless, the participant in our study mentioned that the cuff felt comfortable and was able to rigidly shape and attach to the residual limb.

The participant also noted no increased amount of pressure on the residual limb during maximal contractions, suggesting that the shape of the cuff and the cushion lining were able to spread the pressure evenly through the interface with the leg, even during maximal dynamic effort. Avoiding discomfort and pain during maximal tasks is critical as it has been shown to reduce the force output of muscles in knee extension and flexion tasks [13].

V. Conclusion

Here we presented a novel dynamometer adapter prototype for transtibial amputees. The design requirements for the adapter was to be adjustable to variable lower limb anthropometrics, allow full ROM and be comfortable for the user. The device was tested by a single transtibial amputee. The positive verbal feedback regarding the comfort of the device and the consistent force values obtained suggest that our device is a viable tool for the use of dynamometry in the BKA population. Further testing is needed with a larger sample size and during different types of movement to explore the full potential of the device.

VI. References

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