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TITLE: A Pilot Clinical Trial to Assess the Effect of Transfemoral Socket Design on Hip Muscle Function

PRINCIPAL INVESTIGATOR: Andrew Sawers, CPO, PhD

CONTRACTING ORGANIZATION: University of Illinois at Chicago

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Andrew Sawers CPO, PhD; Stefania Fatone PhD

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13. SUPPLEMENTARY NOTES

14. ABSTRACT: The purpose of the proposed research is to evaluate how prosthetic socket design influences hip muscle function in transfemoral prosthesis users. The scope of the proposed research includes evaluating hip muscle function and its contribution to balance and mobility in unilateral lower limb prosthesis users, and testing whether walking with a sub-ischial socket alters hip muscle function in unilateral lower limb prosthesis users. This is to be accomplished by conducting cross-sectional (aim 1) and longitudinal (aim 2) studies to evaluate hip muscle function in lower limb prosthesis users (aim 1), and test whether it can be influenced by socket design in transfemoral prosthesis users (aim 2). To date we have made completed recruitment, enrollment, and data collection for aim 1 (14 transfemoral, 14 transtibial, and 28 age- and sex-matched controls). We have recruited and enrolled 6 of 8 transfemoral prosthesis users for aim 2. Prospective data collection (baseline, follow up 1 and follow up 2) has been completed for 1 participant. Two other participants have completed baseline and follow up 1, with follow up 2 scheduled for Dec 2021. The remaining three participants have completed baseline testing and are scheduled for follow up 1 and 2 prior to the end of the NCE. Dissemination efforts have resulted in the publication of one manuscript (Hewson et al., 2020), and the submission of a conference abstract (Dent et al., 2020). Two other manuscripts are in preparation. Notable findings from this research to date include: i) the normalization of hip muscle strength by appropriate body parameters alters our understanding of its relationship to balance ability, and reveals between limb differences, and ii) in contrast to popular opinion, residual limb hip muscles are not weaker, but rather stronger than intact hip muscles in unilateral transfemoral prosthesis users.

15. SUBJECT TERMS
amputee; strength; muscle; recruitment; enrollment

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INTRODUCTION

Owing to their design, standard of care ischial-containment sockets may weaken residual limb hip muscles among transfemoral prosthesis users, potentially limiting balance, and mobility. Our recent work has provided anecdotal evidence that walking with a sub-ischial socket (i.e., one that does not interact with the pelvis) increases residual limb hip muscle size and strength in transfemoral prosthesis users. While an appealing therapeutic possibility, direct evidence that socket design alters residual limb hip muscle function among transfemoral prosthesis users is still needed. Testing this hypothesis is made difficult by gaps in our knowledge of muscle function among people with lower limb amputation. The scope of the proposed research therefore includes first evaluating hip muscle function and its contribution to balance and mobility among transfemoral prosthesis users (Aim 1), and then testing the hypothesis that walking with a sub-ischial socket alters hip muscle function among transfemoral prosthesis users (Aim 2). This is to be accomplished by comprehensively evaluating hip muscle strength and endurance in 14 transfemoral ischial-containment prosthesis users and 14 age- and sex-matched able-bodied persons (Aim 1). Eight of the transfemoral prosthesis users will be fit with a sub-ischial socket (Aim 2), and their muscle strength, endurance, and coordination will be assessed eight and 42-weeks post-fitting to evaluate short- and long-term changes in residual limb hip muscle function. This project will determine whether deficits in hip muscle strength or endurance play a causal role in balance and mobility impairments, and may shift the perception of prosthetic sockets from mechanical interfaces to devices with therapeutic benefit (e.g., increase strength).

KEYWORDS

Amputee; muscle; strength; endurance; socket; prospective; rehabilitation

ACCOMPLISHMENTS

Major goals of the project: The major goals (milestones) of the project as outlined in the SOW were:

Goal 1: Obtain and maintain IRB approvals from UIC, NU, and ORP/HRPO
(*Target date: Y1Q1, Y1Q4, Y2Q4 – 100% Completed*).

Goal 2: Study Preparation: recruitment, consent, and data collection materials, equipment, and staff ready for data collection (*Y1Q1- 100% Completed*).

Goal 3: 28 participants enrolled (*Y2Q4 – 100% Completed*).

Goal 4: Data collection completed (*Y2Q3 – 80% Completed*).

- Aim 1 (100% Completed)
- Aim 2 (60% Completed)

Goal 5: Data entered, processed, and analyzed to address study hypotheses (*Y2Q4 – 80% completed*).

- Aim 1 (100% Completed)
- Aim 2 (60% Completed)

Goal 6: Abstracts presented at scientific conferences, manuscripts prepared and submitted for publication, delivery of training material for clinical implementation NU-FlexSIS socket course. (*Y2Q4 – 20% completed*).

Accomplishments under these goals: For each of the goals/milestones outlined in the SOW, we have made significant and timely progress despite the persistent challenges presented by COVID-19 during the past year. With additional safety measures in place we continued recruitment, enrollment, and data collection in an effort to achieve the major goals of the project. These steps have enabled us to meet the goals/milestones of the project, or put us in a position to be able to complete all goals and milestones by the end of the no-cost extension period .

Goal 1: Both study sites (UIC and NU) have completed their annual IRB continuing review, with local approval obtained on and maintained since 07/28/20. Documents for the ORP/HRPO annual continuing review were submitted 06/27/21, and approved on 07/24/21. No cost extension (NCE) documentation were submitted on 06/15/21, and approved 09/14/21, extending the current project until 09/22/22.

Goal 2: The PI and Co-I of the project continue to maintain all study protocols, equipment, and data collection forms. For example the motor driven dynamometer has been regularly serviced and maintained by the manufacturer (i.e., Biodex System 4 Pro (Biodex Medical Systems, Inc., Shirley, NY). New research staff were also trained to assist with data collection at the UIC site with graduation of a student. Recruitment materials were also distributed to additional recruitment sites to expand our enrollment.

Goal 3: For aim 1 (i.e., cross-sectional assessment of hip muscle strength) we have completed all planned recruitment and enrollment. Specifically, over the past year we recruited and enrolled an additional 14 age- and sex-matched controls, for a study total of 28 age- and sex-matched controls. Eight additional transfemoral prosthesis users, for a study total of 14, as well as 8 additional transtibial prosthesis users, for a study total of 14, were also recruited and enrolled. Lower limb prosthesis user participant characteristics are presented in Table 1. While not originally planned, the inclusion of transtibial prosthesis users in aim 1 provides an additional and important comparison to assess how the level of amputation affects hip muscle function. All financial compensation for participants with transtibial amputation is being provided through the PI's discretionary account.

Table 1. Demographic, health, amputation, and mobility-related characteristics of the study sample

Demographic Characteristics		Health Characteristics		Amputation Characteristics			Mobility Characteristics		
Age	Sex	CCI	BMI	Level	Etiology	Time Since Amputation (*years*)	MFCL	PLUS-M (*T-score*)	Prosthetic Use (*hrs/day*)
Mean (95% CI)	Subjects (/28)	Median (MAD)	Mean (95% CI)	Subjects (/28)	Subjects (/28)	Median (MAD)	Subjects (/28)	Mean (95% CI)	Median (MAD)
51.9 (45.6, 58.1)	Male (n=14) Female (n=14)	1.0 (0.74)	27.5 (24.9, 30.2)	Transtibial (n=14) Transfemoral (n=14)	Non-dysvascular (n=21) Dysvascular (n=7)	16.3 (14.1)	K2 (n=10) K3 (n=15) K4 (n=3)	52.4 (48.9, 55.9)	14.5 (3.71)

BMI: Body Mass Index; CCI: Charlson Co-morbidity Index; CI: Confidence Interval; MAD: Median Absolute Deviation; MFCL: Medicare Functional Classification Level (K-level).

For aim 2 (i.e., prospective pilot clinical trial of sub-ischial socket) we recruited and enrolled 4 more transfemoral prosthesis users in the pilot clinical trial. This brings the total number of participants in the 42 week prospective trial to 6 of the originally planned 8 transfemoral prosthesis users. In the past year, the first transfemoral completed the study protocol (i.e., baseline testing, sub-ischial socket fitting and delivery, 8-week follow up testing, and 42-week follow up testing. Participants 2 and 3 have completed baseline testing, received their sub-ischial sockets, and completed their 8-week follow up data collection. Those two participants are scheduled for their final 42-week follow up data collection in February 2022. Subjects 4, 5, and 6 have all completed baseline testing. Subject 4 has been fit with her sub-ischial socket and is scheduled for her 8-week follow up in December 2021. Subjects 5 and 6 have completed their baseline testing, and had their first evaluation/casting appointment for their sub-ischial socket. Sub-ischial sockets will be fit and delivered to both participants within the next quarter, at which point their 8 and 42 week follow up data collections will be scheduled. The demographic, amputation, health, balance, and mobility characteristics of the 6 enrolled participants are presented in table 2. Owing to the interruptions and challenges associated with recruiting transfemoral prosthesis users for a 42-week prospective study during the pandemic, we have elected to cap the pilot clinical trial (Aim 2) sample size at the currently enrolled 6 participants. While we had originally proposed recruiting and enrolling 8 participants, even with the no-cost extension, we would not have sufficient time to complete all 42 weeks of the pilot clinical trial protocol. Nonetheless, we expect that having a full dataset on all 6 currently enrolled participants will provide the results necessary to address the research questions of the pilot clinical trial (i.e., does TF socket design influence hip muscle strength, and if so how (altered recruitment, or increased physical activity). These important data will also be sufficient to serve as pilot data to determine whether a larger, full clinical trial is justified.

Table 2. Aim 2 participant demographic, amputation, and prosthetic-related characteristics

ID	Age	Sex	Weight (kg)	Height (cm)	Race	Ethnicity	Amputation			Prosthesis						
							Level	Time (yrs)	Cause	Socket	SCS	Liner	Suspension	Knee	Pylon	Foot
1	59	M	85.1	178.5	W	Not Hispanic or Latino	TF	7	Cancer	IC	4	Seal in X5	Suction	C-leg 4	Torsion	Maverick Comfort AT
2	20	M	63.5	170.2	W	Hispanic or Latino	TF	3.5	Trauma	IC	8	Seal in X5	Suction	C-leg	Standard	Triton VS
3	44	F	72.6	157.5	AA	Not Hispanic or Latino	TF	6	Trauma	IC	6	Seal in conical	Suction	C-leg	Standard	Otto Bock Meridium
4	51	F	53.5	167.0	W	Not Hispanic or Latino	TF	32	Trauma	IC	7	Seal in standard	Suction	C-leg 4	Torsion	Proflex Align
5	29	F	76.3	167.3	AA	Not Hispanic or Latino	TF	2.5	Other	IC	6	Seal in conical	Suction	C-leg 4	Standard	Fillauer Aeris
6	73	M	86.5	180.1	AA	Not Hispanic or Latino	TF	6	Other	IC	5	Seal in conical	Suction	C-leg 4	Torsion	Otto Bock Trias

M: male; F: female; W: white; AA: African American; TF: transfemoral; L: left; R: right; IC: ischial containment;

Goal 4: Over the past year we collected hip muscle strength, as well as clinical walking and balance data on the remainder of our planned sample for aim 1. Specifically, an additional 8 transfemoral amputees, 8 transtibial amputees, and 14 age- and sex-matched controls completed data collection for aim 1. These efforts bring the study totals for aim 1 to 14 transfemoral, 14 transtibial, and 28 age- and sex-matched control participants. Despite the difficulties presented by the pandemic, our additional efforts and success at recruitment and data collection have enabled us to perform important analysis regarding the normalization of strength data in lower limb prosthesis users, as well as initial analyses comparing hip muscle strength across residual, intact, and control limbs (see Goal 5 below for details).

For aim 2 we collected baseline strength, electromyography, and clinical walking and balance data on an additional 4 transfemoral participants, bringing the study total to 6 of the planned 8 transfemoral prosthesis users.. We have also completed the 8-week follow-up testing after sub-ischial socket fitting (i.e., hip muscle strength, electromyography, and walking and balance performance) on 3 of the 6 transfemoral prosthesis users, and the 42-week follow up data collection on 1 transfemoral prosthesis users. We anticipate completing the remaining data collection sessions for aim 2 over the no-cost extension period.

Goal 5: We recently completed our analysis investigating the need for, and influence of normalization on hip strength in unilateral lower limb prosthesis users. Our recently published review of muscle strength in lower limb prosthesis users (Hewson et al., 2020) noted that only 2 of the 12 currently published articles normalized muscle strength measures by key body parameters (e.g., body mass, segment length, body size) (Lloyd, 2020; Rutkowska, 2018). Further, both of those studies normalized their strength data to body mass without confirming that there was a significant association between strength and body mass in lower limb prosthesis users. Normalization of strength data by body parameters is important because it allows for fair comparisons between people and legs that differ in size and shape. Failure to normalize strength data may therefore confound or alter the interpretation of important relationships between strength and walking or balance ability, as well as between limb differences in amputees. To address this gap, our analyses focused on three key questions: i) is hip strength, estimated via peak torque, significantly associated with (i.e., dependent on) body parameters in LLP users? (i.e., "is normalization required"), ii) does normalization reduce any significant associations between peak hip torques and body parameters in LLP users? (i.e., "does normalization work"), and iii) does normalization alter the interpretation of strength data (i.e., peak hip torque) in unilateral lower limb prosthesis users? (i.e., "what are the consequences of failing to normalize strength data in LLP users"). To determine whether hip strength was associated with common body parameters we performed a series of regressions between the log of non-normalized peak hip torques collected on a motor driven dynamometer and the log of a host of body size parameters (e.g., body mass, thigh length, and body size). When the 90% confidence interval of the slope of the resulting regression line includes 1, but not zero, this can be interpreted as a significant association between the hip strength measure and body parameter. We found that non-normalized hip extension and abduction strength, in both the residual and intact legs, were significantly associated with thigh length as well as body size (i.e., body mass x thigh length), but not consistently with body mass. For example, Figure 1 depicts the regression between the log of non-normalized peak hip abduction torque in the residual limb and the log of body size (body mass x thigh length). The resulting regression line had a slope of 0.66, with a 90% confidence interval of 0.15 to 1.2. Thus,

because the confidence interval around the slope contained 1 but not zero, the slope was determined to be significantly different than zero (i.e., equal to 1), suggesting a significant association between peak hip abduction torque in the residual limb and body size.

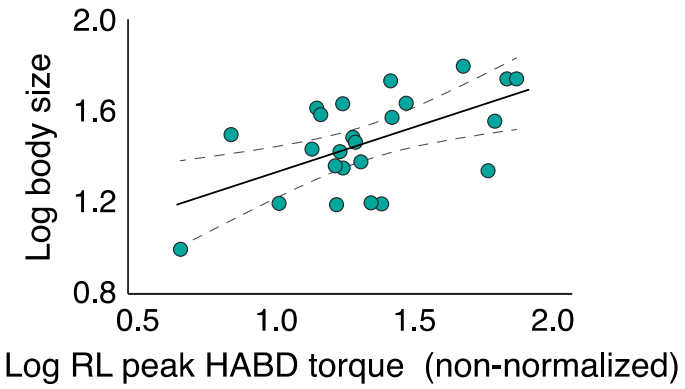


Figure 1. Regression between the log of body size and the log of residual limb non-normalized peak hip abduction torque. The resulting slope of the regression line was 0.66, with a 90% confidence interval of 0.15 to 1.2. Because the confidence interval for the slope of the line included 1, but not zero, the two variables are considered to be significantly associated with each other, suggesting a dependency of residual limb peak hip torque and body size in transfemoral prosthesis users.

The results of the regressions between the remaining non-normalized hip torques and body parameters are presented in table 3. Those regressions found to be significant, and thus indicating a significant association between non-normalized hip torque and body parameters, are marked with an asterisk.

Table 3. The slopes (ß) and accompanying 90% confidence intervals (CI) of linear regressions between the logarithm of *non-normalized* hip extensor and abductor muscle strength (estimated as maximum voluntary isometric peak torque) and the logarithm of body mass, segment (i.e., thigh) length, or body size.

	Hip extensors		Hip abductors	
	residual limb ß (90% CI)	intact limb ß (90% CI)	residual limb ß (90% CI)	intact limb ß (90% CI)
Body mass	.46 (-.49,1.4)	.56 (-.20,1.3)	.39 (-.49,1.3)	.69 (.04,1.3)*
Thigh length	.97 (.18,1.8)*	4.4 (1.6,7.1)*	1.0 (.29,1.7)*	4.0 (.77,7.3)*
Body size	.67 (.11,1.2)*	.68 (.10,1.4)*	.66 (.15,1.2)*	.66 (.09,1.2)*

Based on these results, the answer to our first question is, yes, residual and intact limb peak hip torques are significantly associated with (dependent on) body size and thigh length, but importantly not body mass, which has been commonly used for normalization in previous research.

Next, to determine whether normalization reduces the association between peak hip torques and body size or thigh length in LLP users we performed a second series of log-log regressions. These

regressions however were between the hip torques normalized (i.e., divided by each body parameter) and that body parameter. Importantly, here we were looking for 90% confidence intervals around the slope of the log regression line that included 0, but not 1 (i.e., a slope that was not significantly different from zero). We found that normalization of peak hip torques by body size, but not thigh length, consistently and significantly reduced associations (i.e., slope of the log regression lines were not significantly different from zero). Figure 2 depicts how the normalization of peak hip abduction torque in the residual limb by body size removes any association with that body parameter (i.e., compare the slope of the line in figure 2 to that in figure 1).

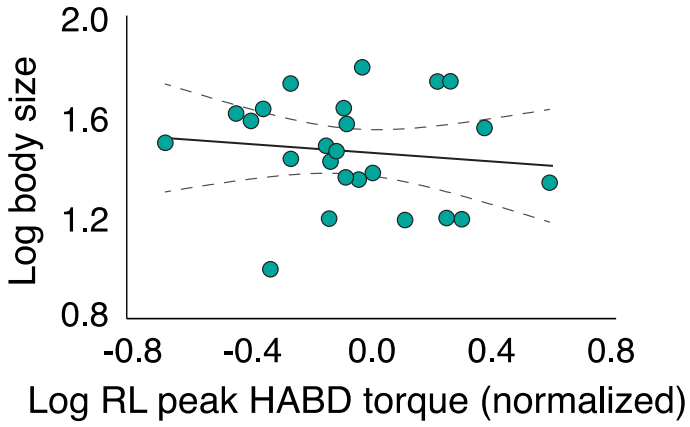


Figure 2. Regression between the log of body size and the log of residual limb peak hip abduction torque normalized by body size. The resulting slope of the regression line was -.35, with a 90% confidence interval of -.85 to 0.16. Because the confidence interval for the slope of the line did not include 1, only zero, the slope of the line was not significantly different than zero, suggesting that any association between residual limb peak hip torque and body size in transfemoral prosthesis users is removed.

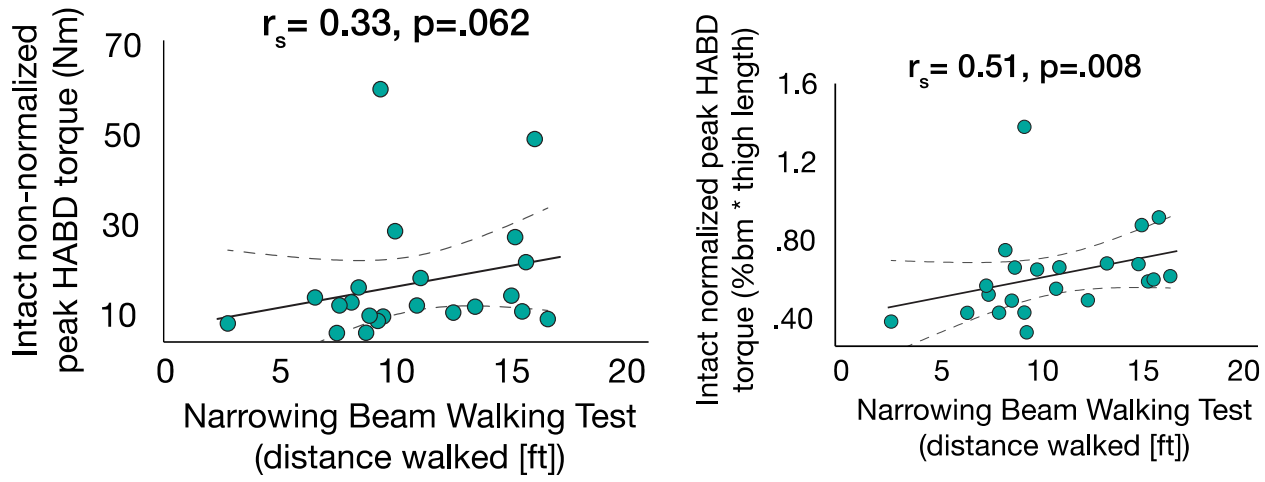
The results of the regressions between the remaining normalized hip torques and body parameters are presented in table 4. Those regressions found to be significant, suggest that normalization has removed any significant association between hip torque and body parameters, are marked with an asterisk.

Table 4. The slopes (ß) and accompanying 90% confidence intervals of linear regressions between the logarithm of *normalized* hip muscle strength (estimated as maximum voluntary isometric peak torque) and the logarithm of body mass, segment (i.e., thigh) length, or body size.

	Hip extensors		Hip abductors	
body parameters	residual limb ß (90% CI)	intact limb ß (90% CI)	residual limb ß (90% CI)	intact limb ß (90% CI)
Body mass	--	--	--	-.31(-.96,.34)*
Thigh length	-.03 (-.82,.75)*	3.4 (.61,6.1)	.001 (-.71,.71)*	3.0 (.22,6.3)
Body size	-.34 (-.89,.22)*	-.32 (-.98,.35)*	-.35 (-.85,.16)*	-.34(-.91,.23)*

Based on these results, the answer to our second question is, yes, normalization of residual and intact limb peak hip abduction and extension torques by body size, but not thigh length, removes significant associations in the strength data with body parameters.

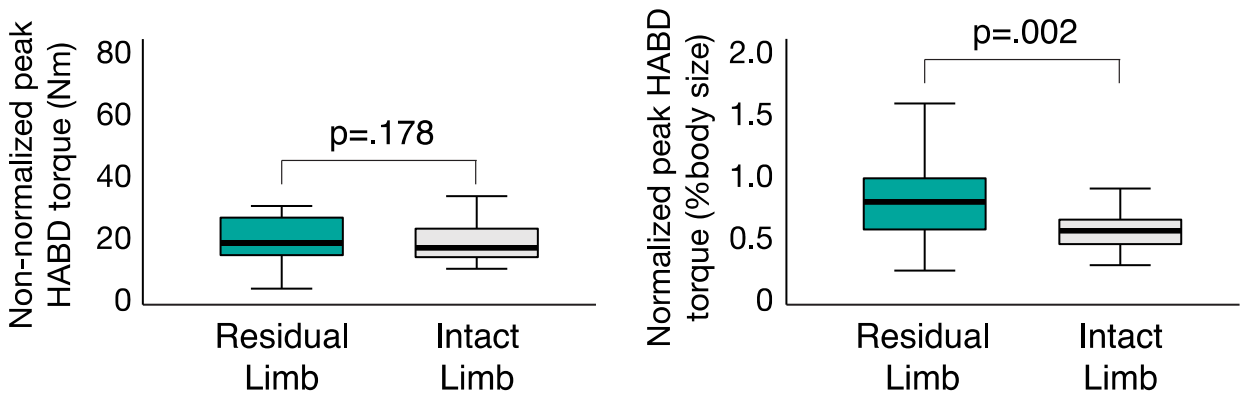
Finally, to determine whether normalization by body size alters the interpretation of strength data (i.e., peak hip torque) in unilateral lower limb prosthesis users we compared the strength of the correlation between intact leg peak hip abduction torque (non-normalized and normalized to body size) to balance performance on the Narrowing Beam Walking Test. We also compared between limb differences (residual limb vs. intact limb) in peak abduction strength before and after normalization by body size. We found that normalization of intact limb peak hip abduction torque increased the correlation magnitude, and made it significant (Figure 3). We also found that after normalizing residual and intact peak hip abduction torque by body size, between limb differences, which were not previously significant, were significant (Figure 4). These results suggest that normalization of peak hip abduction torque by body size alters its relationship to balance ability and reveals between limb differences that would otherwise be overlooked.



Figures 3 and 4. The normalization of peak hip abduction torque in the residual limb by body size (body mass x thigh length) increased the magnitude and significance of the correlation between hip abduction strength and balance performance as assessed on the Narrowing Beam Walking Test (valid and reliable balance test in LLP users). Failure to normalize hip strength data in LLP users may therefore mask important relationships between hip strength and walking or balance performance.

Based on these results, we conclude that peak hip abduction and extension torques in unilateral lower limb prosthesis users should be normalized to body size (body mass x thigh length) to allow for fair comparisons between LLP users of different sizes, as well as between legs of different sizes (e.g., residual vs. intact legs). These results are highly relevant to future research and our understanding of muscle function in lower limb prosthesis users because they suggest that much of what we know about muscle strength in lower limb prosthesis users could be incorrect, as the bulk of the research to date has been conducted without normalizing strength data. These results are being presented as a poster at the 2021 ISPO World Congress November 1-4 (Appendix 2). We also anticipate submitting a manuscript for peer-review by the end of the quarter.

Having completed our normalization analysis, we were able to begin our analysis of between limb differences in hip strength among transfemoral prosthesis users and age- and sex-matched controls (Aim 1). Using a mixed-ANOVA (i.e., within subject factor of muscle, and between subject factor of leg), we identified a novel and thought provoking pattern of hip muscle strength in transfemoral prosthesis users. Specifically, we found that in contrast to popular opinion, and previous research, the residual limb of transfemoral amputees was actually stronger than their intact limb, not weaker (Figure 5). Further, the residual limb hip muscles were also stronger than those of age- and sex-matched controls. This stands in stark contrast to previous research suggesting that residual limb hip muscles in transfemoral prosthesis users were weaker than their intact muscles.



Figures 5. The normalization of peak hip abduction torque in the residual and intact limbs by body size (body mass x thigh length) revealed a significant between limb difference in abduction strength that would have otherwise been overlooked (i.e., in the absence of normalization).

Figure 5 also reveals that hip muscles in the intact limb are significantly weaker than those of age- and sex-matched controls. Overall, these results suggest that it is the strength of the intact limb hip muscles, not those of the residual limb that are the limiting factor in transfemoral prosthesis users.

Goal 6: We authored a conference abstract based on the strength normalization data analysis. This abstract will be presented at= the World Congress of the International Society for Prosthetics and Orthotics in November. We also plan to submit a separate abstract to the 2022 International Society of Posture and Gait Research based on our between limb strength differences among transfemoral prosthesis users and age- and sex-matched controls. In addition of our normalization manuscript, and several others are currently in preparation. These include: i) hip muscle strength profiles in transfemoral prosthesis users (described above), ii) hip muscle strength profiles in transtibial prosthesis users, iii) the relationship between hip strength and walking and balance performance in unilateral lower limb prosthesis users, and iv) a second review paper synthesizing reported changes in muscle structure with amputation.

Opportunities for training and professional development: Nothing to report.

Dissemination of results to communities of interest: Nothing to report.

Plan to accomplish goals during over next reporting period: During the no-cost extension we intend to complete all remaining facets of the study goals. This includes: i) completing data collection for Aim 2; ii) completing data analysis for aim 2; iii) conducting hypothesis testing for Aim 1 and additional questions we have developed; iv) prepare and submit manuscripts related to Aim 1; v) conducting hypothesis testing for Aim 2; vi) prepare and submit manuscripts related to Aim 2; iv) present study results to local prosthetists in the Chicago area at the 2021 Scheck and Siress Education Fair, as well as the ISPGR world congress.

IMPACT: Nothing to report.

CHANGES/PROBLEMS
Nothing to report.

PRODUCTS
Journal publications (in this reporting period)
N/A

Conference presentations (in this reporting period)
Dent SR, Fatone S, Sawers A. Normalization alters the interpretation of between limb differences in peak isometric hip extension torque among lower limb prosthesis users. *International Society of Prosthetics and Orthotics World Congress*. Nov 1-4 2021 (*Poster*).

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS
Individuals who worked on the project

Name:	Andrew Sawers, PhD
Project Role:	Principal Investigator (UIC)
Researcher Identifier:	
Nearest person month worked:	1
Contribution to Project:	Dr. Sawers has been responsible for overseeing all aspects of the project (IRB, managing recruitment, enrollment, and data collection, data analysis, and manuscript preparation)
Funding Support:	N/A

Name:	Stefania Fatone, PhD
Project Role:	Co-Investigator (NU)
Researcher Identifier:	
Nearest person month worked:	<1
Contribution to Project:	Dr. Fatone has been responsible for overseeing aspects of the project at the NU study site (IRB, managing recruitment, enrollment, and socket fabrication and fitting).
Funding Support:	N/A

Name:	Shaquitta Dent, MS
Project Role:	Graduate Student (UIC)
Researcher Identifier:	
Nearest person month worked:	1
Contribution to Project:	Ms. Dent has performed work in the area of screening of participants, enrolling participants, consent, data collection, data entry, and data analysis at the University of Illinois at Chicago study site.
Funding Support:	N/A

Name:	Ryan Caldwell
Project Role:	Co-I (NU)
Researcher Identifier:	
Nearest person month worked:	<1
Contribution to Project:	Mr. Caldwell has been responsible for overseeing aspects of the project at the NU study site (recruitment as well as socket fabrication and fitting).
Funding Support:	N/A

Change in the active other support for the PD/PI(s) or senior/key personnel

Dr. Stefania Fatone, study co-investigator at Northwestern University, has recently accepted a new position at the University of Washington. Her critical responsibilities as study co-I regarding recruitment and enrollment for this project have been completed. Her remaining responsibility relates to dissemination efforts, which she will continue with. Rather than take the subcontract with her to the University of Washington during the no-cost extension year, the sub-contract will remain with Northwestern University. This will allow us to continue to compensate Ryan Caldwell (the study prosthetist) for his time building and fitting sockets as part of Aim 2, and compensate those participants he works with during the no-cost extension period. Additionally, with Dr. Fatone moving on to her new position at the University of Washington, Northwestern has assigned Steve Gard PhD, to perform any remaining administrative duties associated with the project (e.g., close out IRB, submit sub-contract quarterly reports to study PI). We do not anticipate that this will have any effect on our ability to successfully complete the proposed work.

Other organizations involved as partners

Nothing to report

SPECIAL REPORTING REQUIREMENTS

N/A

APPENDICES

Appendix 1: Quad Chart

Appendix 2: ISPO Poster

A pilot clinical trial to assess the effect of transfemoral socket design on hip muscle function

OP180022

W81XWH-19-1-0507-OPORP-PORA (Funding Level 1)

PI: Andrew Sawers, PhD, CPO **Org:** The University of Illinois at Chicago **Award Amount:** $350,000

Study Aim(s)

- Evaluate hip muscle function and its contribution to balance and mobility among unilateral transfemoral prosthesis users.
- Test whether walking with a sub-ischial socket alters hip muscle function among unilateral transfemoral prosthesis users.

Approach

We will conduct cross-sectional (Aim 1) and longitudinal (Aim 2) studies to evaluate hip muscle function in transfemoral prosthesis users, and test whether it can be influenced by socket design. We will compare measures of hip muscle strength between transfemoral amputees and controls, while evaluating the relationship between hip muscle function and walking and balance performance among transfemoral amputees (Aim 1). We will also prospectively assess changes in measures of hip muscle function among transfemoral amputees transitioning from an ischial-containment to a sub-ischial socket (Aim 2).

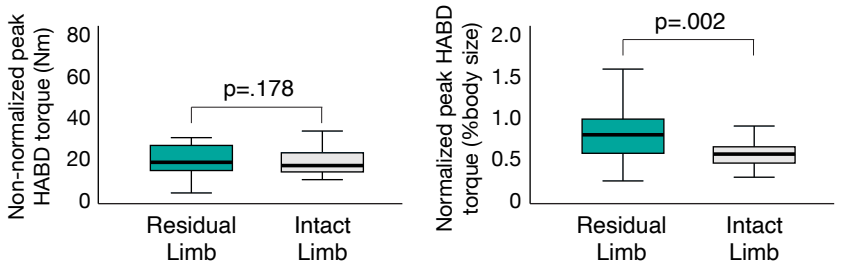


Figure. Effect of normalization by body size on between limb differences in hip abduction strength in unilateral lower limb prosthesis users. The normalization of peak hip abduction torque in the residual and intact limbs by body size (body mass x thigh length) revealed a significant between limb difference in abduction strength that would have otherwise been overlooked (i.e., in the absence of normalization). This result demonstrate the importance of normalization, and how failure to normalize strength data in lower limb prosthesis users to the appropriate body parameter can mask important between limb differences in strength.

Timeline and Cost

Activities	CY	19	20	21
Human subjects approval & train sites				
Participant recruitment				
Conduct data collection procedure				
Analyze data and disseminate results				
Estimated Budget ($K)	**$350**	**$100**	**$150**	**$100**

Updated: (07/27/2021)

Goals/Milestones

CY19 Goal – Study preparation and participant recruitment

- ☑ Obtain local human subjects approval
- ☑ Finalize protocols, data collection sheets and study database
- ☑ Equip and train study staff at UIC & Northwestern

CY20 Goals – Ongoing recruitment, data collection, and analysis

- ☑ Recruit 28 participants for Aim 1
- ☐ Recruit 8 participants for Aim 2
- ☑ Conduct data collection and analysis procedures
- ☑ Disseminate initial results at national conference

CY21 Goal – Analysis and dissemination

- ☑ Recruit and collect data from final 10 participants
- ☐ Analyze final data set
- ☐ Disseminate final study results

Comments/Challenges/Issues/Concerns

- None to report

Budget Expenditure to Date

$185,264 (including F&A)

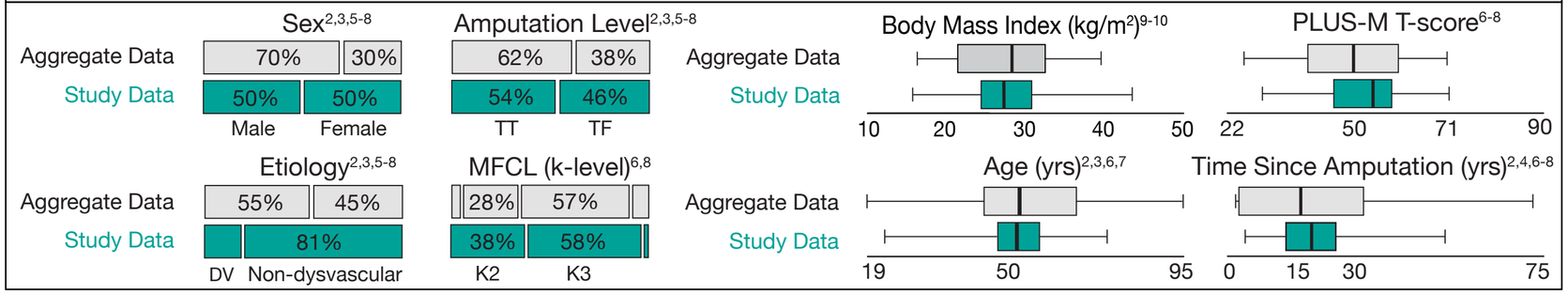
Normalization of peak hip torque may alter the interpretation of hip strength in established unilateral lower limb prosthesis users

Shaquitta Dent[1], Stefania Fatone[2], Andrew Sawers[1]
(1) University of Illinios-Chicago, (2) Northwestern University

Motivation: Normalization of strength data is uncommon in lower limb prosthesis (LLP) user researcher, potentially causing us to overlook important relationships between strength and walking or balance ability, as well as critical between limb differences.

- A recent review of muscle strength in LLP users[1] noted that only a quarter of the studies normalized strength data by key body parameters (e.g., body mass, height, segment length). Normalization by body parameters is important because it allows for fair comparisons between people and legs that differ in size and shape. Failure to normalize strength data may confound or alter the interpretation of important results.
- The **objective** of this pilot study was to address this gap by answering 3 questions: i) is normalization of strength data required in LLP users, ii) does normalization "work" (ie., reduce influence of body parameters), and iii) what are the consequences of failing to normalize strength data?

Result 1: Sample characteristics (n=26) were largely consistent with those from larger studies of lower limb prosthesis (LLP) users

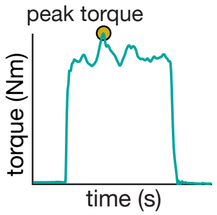


Approach: Maximum vountary isometric hip extension (HEXT) and abduction (HABD) torques were recorded from 26 LLP users.

1. Data Collection (motor-driven dynamometer)

Positioning
- HABD: side-lying, 10°
- HEXT: supine, 20°
- Prosthesis removed

Testing
- Three practice trials
- Fifteen 5s trials, 10s rest
- Muscle & leg randomized



2. Data Acquisition and Processing

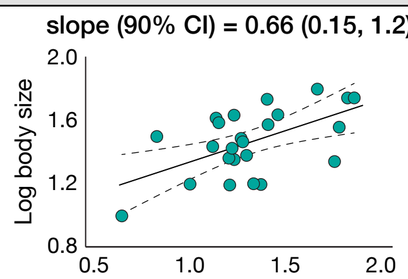
- Dynamometer analog signal sampled at 1000Hz
- Torque signal converted from volts to Nm, corrected for gravity, and low-pass filtered (Svetsky-Golay)
- Peak torque detected between signal onset / offset

3. Normalization Procedure

Power function: $Y = AX^{\beta}$ $\xrightarrow[log]{linearize}$ $\log Y = \log A + \beta(\log X)$ $\rightarrow$ $A = YX^{-\beta}$

Y = non-normalized torque *X = body parameter*
A = normalized torque *β = scaling constant (slope)*

Result 2: Is hip strength, estimated by peak torque, significantly associated with (dependent on) body parameters in LLP users?



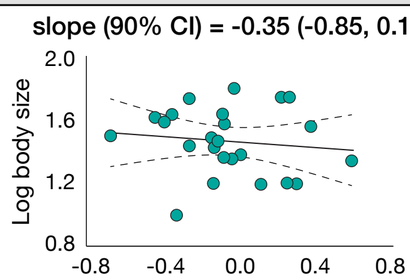
body parameters	Hip extensors: residual limb ß (90% CI)	Hip extensors: intact limb ß (90% CI)	Hip abductors: residual limb ß (90% CI)	Hip abductors: intact limb ß (90% CI)
Body mass	.46 (-.49,1.4)	.56 (-.20,1.3)	.39 (-.49,1.3)	.69 (.04,1.3)*
Thigh length	.97 (.18,1.8)*	4.4 (1.6,7.1)*	1.0 (.29,1.7)*	4.0 (.97,7.3)*
Body size	.67 (.11,1.2)*	.68 (.10,1.4)*	.66 (.15,1.2)*	.66 (.09,1.2)*

*Confidence intervals around the slope of log regressions relating non-normalized torque to body size or thigh length did not include 0.

Residual and intact limb peak hip torques were significantly associated with (dependent on) body size and thigh length

Effect of normalization on association between RL HABD and body size

Result 3: Does normalization reduce the association between peak hip torques and body size or thigh length in LLP users?

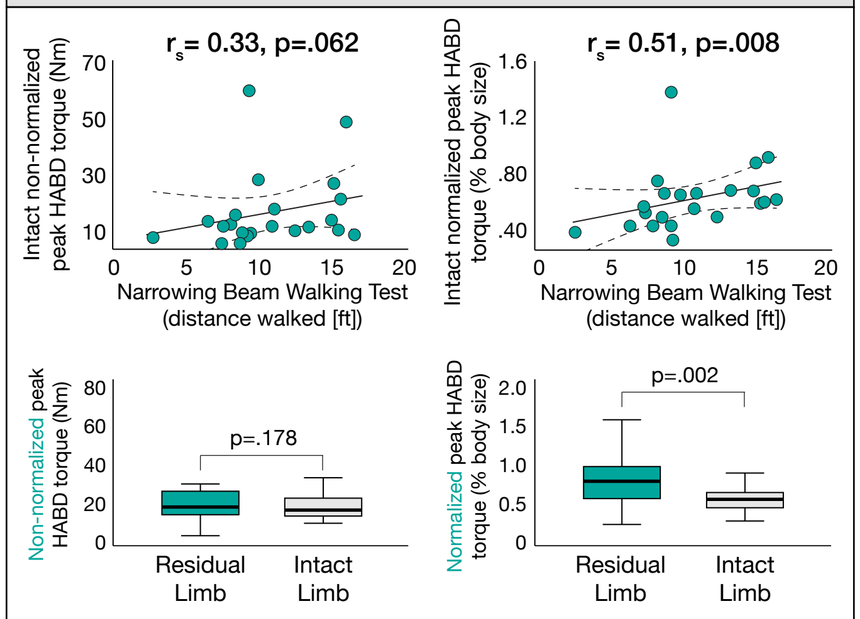


body parameters	Hip extensors: residual limb ß (90% CI)	Hip extensors: intact limb ß (90% CI)	Hip abductors: residual limb ß (90% CI)	Hip abductors: intact limb ß (90% CI)
Body mass	--	--	--	-.31(-.96,.34)*
Thigh length	-.03 (-.82,.75)*	3.4 (.61,6.1)	.001 (-.71,.71)*	3.0 (.22,6.3)
Body size	-.34 (-.89,.22)*	-.32 (-.98,.35)*	-.35 (-.85,.16)*	-.34(-.91,.23)*

*Confidence intervals around the slope of the log regressions between normalized torque and body size consistently included 0, but not 1.

Normalization of peak hip torques by body size consistently and significantly reduced associations, enabling comparisons

Result 4: Does normalization alter the interpretation of hip strength (i.e., peak hip torque) in unilateral LLP users?



Normalization of hip abduction torque by body size alters its relationship to balance ability & reveals between limb differences

Peak hip abduction and extension torques in unilateral LLP users should be normalized to body size (body mass x thigh length)

- Failure to normalize strength data (i.e., peak torque) in LLP users may confound results, alter their interpretation, and influence the treatments and questions clinicians and researchers pursue.
- Further research with a larger sample, additional strength measures, alternative normalization procedures, and other muscle groups is required.

References and Funding Sources

1) Hewson et al., 2020 POI; 2) Ehde et al., 2000 Arch Phys Med Rehabil; 3) Pezzin et al., 2004 Arch Phys Med Rehabil; 4) Ephraim et al., 2005 Arch Phys Med Rehabil; 5) Ziegler-Graham et al., 2008 Arch Phys Med Rehabil; 6) Hafner et al.,2016 J Rehabil Res Dev; 7) Wurdeman et al., 2018 Am J Phys Med Rehabil; 8) ABC Practice Analysis, 2015; 9) Frost et al., POI 2017; 10) Wong et al., 2019 Am J Phys Med Rehabil.

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