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Physical and functional measures related to low back pain in individuals with lower-limb amputation: An exploratory pilot study

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Abstract—For this study, we compared the physical impairments and functional deficits of individuals with lower-limb amputation (LLA) for those with and without low back pain (LBP). Nineteen participants with LLA were placed into two groups based on visual analog scores of LBP. We assessed functional limitations, iliopsoas length, hamstring length, abdominal strength, back extensor strength, and back extensor endurance. Data analysis included correlations and *t*-tests. We found significant correlations between pain score and functional limitations, iliopsoas length, and back extensor endurance. We also detected significant differences in functional limitations, iliopsoas length, back extensor strength, and back extensor endurance between those with and without LBP. We saw significant differences in back extensor strength and back extensor endurance between those with transtibial and transfemoral amputations. Differences exist in physical measures of individuals with LLA with and without LBP. Clinicians should consider these impairments in individuals with amputation who experience LBP. Because of the participants' characteristics, these findings may be applicable to veterans with LLA.

Key words: amputation, disability, low back pain, lower limb, phantom pain, prosthesis, rehabilitation, residual limb pain, veterans, visual analog scale.

INTRODUCTION

Low back pain (LBP) is a common condition, with 50 to 90 percent of the general population experiencing some degree of LBP during their lifetime [1–2]. Causes of LBP have been studied extensively and include musculoskeletal impairments, biomechanical abnormalities, gait deviations, primary medical causes, and deleterious or excessive activity [3–7].

Pain after lower-limb amputation (LLA) has been studied. Typically, investigators examine the incidence and causes of residual-limb pain, phantom pain, and pain experienced from the use of the prosthesis. Smith and colleagues [8] and Ehde and colleagues studied the prevalence of LBP postamputation [9], finding that 71 percent of participants reported LBP in the month preceding the study. They found that the prevalence was similar to participants reporting nonpainful phantom sensations (75.7%) and residual-limb pain (76.1%) [8]. Additionally, participants rated their LBP as being more bothersome

Abbreviations: ANOVA = analysis of variance, LBP = low back pain, LLA = lower-limb amputation, NYIT IRB = New York Institute of Technology Institutional Review Board, PKE = passive knee extension, SD = standard deviation, SPSS = Statistical Package for the Social Sciences, VAS = visual analog scale.

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than either phantom pain or residual-limb pain [8]. While phantom sensations and residual-limb pain are commonly addressed in the rehabilitation of the patient with LLA [10–13], we could find only one reference to treatment of LBP in this population, with Esquenazi and DiGiacomo [10] recommending activities to maintain trunk flexibility.

Because of the prevalence of LBP after amputation, it is important to investigate possible causes, such as biomechanical changes secondary to the amputation, including muscle imbalances thought to be common in individuals after amputation and changes in gait patterns secondary to the use of a lower-limb prosthesis [14–20].

In addition to these factors unique to persons with LLA, these individuals may also exhibit physical characteristics thought to be related to the development of nonspecific LBP in the general population. These physical characteristics include deficiencies in abdominal muscle strength, back extensor muscle strength, back extensor muscle endurance, hamstring muscle flexibility, and iliopsoas muscle length [3–6,21–22]. Despite the association of these measures with LBP in the general population, they have not been studied in individuals with LLA.

Therefore, for this study we explored whether these physical measures are more impaired in individuals with LLA and LBP than in those with LLA without LBP. Our secondary purpose was to explore whether a difference existed in these measures between participants with transtibial and transfemoral amputation.

In general, specific strength and length variables were selected because muscle imbalances may cause abnormal biomechanics, which may then cause compensatory movements, leading to microtrauma in the pelvis and lumbar spine [7]. Because of the linking of the pelvis, torso, and lower limbs in gait, repetitive strain injury to the lumbosacral spine is possible with improper or altered gait [23]. We chose muscles that function in the sagittal plane of motion for this study, because they have been shown to be important in gait after LLA [18,24] and in the development of lumbar lordosis [7].

In summary, physical characteristics associated with the development of LBP in the general population include decreased iliopsoas and hamstring muscle length, weakness of abdominal and back extensor muscles, and decreased back extensor muscle endurance. For this study, we determined whether these characteristics are associated with LBP in individuals with LLA.

METHODS

An ex postfacto design was developed and approved by the New York Institute of Technology Institutional Review Board (NYIT IRB).

Participants

From a potential pool of approximately 60 people, 21 participants were recruited and 19 completed the study. We obtained the convenience sample from support groups for persons with amputation, at a golf outing for persons with amputation, and through referrals from prosthetists. Inclusion criteria included individuals with a unilateral transfemoral or transtibial amputation who were more than 18 months postamputation and ambulatory with a prosthesis. Exclusion criteria included other amputation levels, back or hip pain requiring intervention before the amputation, or a history of back surgery. All participants gave their informed consent as outlined in the proposal approved by the NYIT IRB. The two individuals who did not complete the study were found to be ineligible during the measurement process.

The 19 individuals were 16 men and 3 women with an average age of 56.5 years (SD [standard deviation] = 14.3 years). Eleven participants had a transtibial amputation and eight had a transfemoral amputation. Disease (11 participants) and trauma (8 participants) were the causes of amputation. The average time since amputation was 11.8 years (SD = 9.33 years).

Instruments

Pain Intensity

The visual analog scale (VAS), a reliable and valid tool [25–27], measured pain intensity. Participants were asked to make a notation on a blank line corresponding to pain level within the last week, with the anchors indicating “no pain” and “severe pain.” We chose a short period of time for intensity of pain to correspond closely to the measurements taken within this study.

Back Pain Disability

We calculated back pain disability during the month preceding participation in the study with the Revised Oswestry Low Back Pain Disability Questionnaire (Oswestry). The time frame for this measurement was longer than for the VAS because we felt that not all participants would perform all the functional tasks in a 1-week period. The revised Oswestry, designed to assess the influence of

LBP on activities of daily living and leisure functions, has been shown to have a high degree of test-retest reliability and internal consistency [28]. The Oswestry consists of 10 sections covering aspects of daily living that may be affected by LBP. The items in each section are scored from 0 to 5, totaled, and converted to a percentage of disability score based on the number of items answered. Scores range from 0 to 50, and higher scores indicate greater levels of functional difficulties.

Iliopsoas Muscle Length

We measured the length of the iliopsoas muscles bilaterally with the Thomas test [29]. Tightness was indicated by an angle between the thigh and the supporting surface when one thigh was lowered passively while the other thigh was held to the chest. We measured this angle with a goniometer with the axis at the greater trochanter, the stationary arm aligned with the trunk, and the moving arm aligned with the femur.

Hamstring Muscle Length

We determined hamstring flexibility through the 90/90 straight leg raise passive knee extension (PKE) test [3], which has been shown to have excellent test-retest reliability [30]. Participants were positioned supine with the tested leg's hip flexed to 90°. We passively moved the knee into extension. Once the examiner felt soft tissue resistance, we measured the angle at the knee with a goniometer with the axis at the lateral femoral epicondyle, the stationary arm vertical, and the moving arm in line with the fibula. We assessed the participants' bilateral lower limbs with transtibial amputation, and we performed uninvolved limb testing on the participants with transfemoral amputation.

Abdominal Muscle Strength

We measured upper-abdominal strength with the trunk-raising test, which applies different loads with a change of arm position during the trunk raise, as described and graded according to Palmer and Epler [29]. All participants were asked to begin the test at a middle grade. Depending on the performance on that trial, subsequent attempts were either harder or easier until a level of maximal performance was reached.

Back Extensor Muscle Strength

We assessed back strength with the prone-lying trunk-raising test [31]. Straps provided stabilization across the buttocks and the tibial region, with additional manual stabilization across the upper-thigh region, if needed. Scoring was as follows:

0—No contraction of back extensor muscles palpated.
1—Flicker of a muscle contraction is palpable.
2—Arms by the sides, the patient lifts the head and upper sternum off the plinth.
3—Hands held behind low back, xiphoid process is off the plinth.
4—Hands behind the low back, mid- to lower-abdominal region clears the table.
5—Hands behind the head, mid- to lower-abdominal region clears the table.

All participants were asked to begin the test by attempting a grade of 3. Depending on the performance on that trial, subsequent attempts were either harder or easier until a level of maximal performance was reached.

Back Extensor Muscle Endurance

We measured back extensor muscle endurance with the Sorensen test [3–4]. The patient was positioned prone on a plinth, up to the upper borders of the iliac crests with the lower limbs strapped, as in the back extensor muscle strength test. We provided initial stabilization of this position by having the patient lean on a chair at the edge of the plinth with the upper limbs. We applied additional manual stabilization over the upper thighs for the test. The patient was asked to bring the arms across the chest and hold the unsupported upper body in a horizontal position for as long as possible. When the torso deviated more than 6° from the stable position for more than 6 s, the test was terminated. With a stopwatch, we measured the time in seconds that the subject was able to hold the stable position. We held a goniometer against the subject's torso to determine deviations from the stable position. Normative holding time has been reported in other studies to be between 180 s and 196 s for healthy unimpaired participants [32–33].

Procedures

Before taking the physical measurements, researchers introduced the study to prospective participants, secured informed consent, completed a demographic information form with the participants, and provided specific instructions to these individuals on how to complete the Oswestry and the VAS. Then, each subject was evaluated for each of the physical variables: iliopsoas muscle length, hamstring muscle length, abdominal

muscle strength, back extensor muscle strength, and back extensor muscle endurance. The prosthesis remained on for all measures. One researcher, who was unaware of the scores on the VAS and Oswestry, performed all measurements.

Data Analysis

Data were analyzed with Statistical Package for the Social Sciences (SPSS) 10.0 for Windows. We averaged the iliopsoas measures for each participant to obtain a single iliopsoas score for each. We performed a similar transformation for the hamstring muscle length measure for those with transtibial amputation. For those with a transfemoral amputation, we took measurements of the sound limb.

To explore the association between physical variables and LBP, we calculated bivariate correlations between pain, disability, and physical variables. Then, we performed tests of differences between those participants with and those without LBP for all variables. We conducted some additional *t*-tests to examine the impact of possible confounding variables.

To determine whether differences could be found in the physical variables between individuals with and without LBP, we first had to determine how to place them into groups. This proved to be difficult, because a systematic review of prevalence studies on LBP by Leboeuf-Yde and Lauritsen [34] found virtually no agreement among researchers regarding the definition of LBP. Very few studies reported the exact criteria used to determine the presence of LBP. Because of this lack of consensus, we chose to create two different pain groups to explore the phenomenon more fully. In what we have labeled as the pain-2 variable, individuals who scored less than 2 cm on the VAS in relation to back pain within the past week were placed into the "minimally painful" group ($n = 10$), with all others placed into the "painful" group ($n = 9$) for analysis. In what we have labeled as the pain-5 variable, individuals who scored less than 5 cm were placed into the "minimally painful" group ($n = 15$) with all others placed into the "painful" group ($n = 4$). We made comparisons between groups with the independent *t*-test. Because of the exploratory pilot nature of this study, we selected an alpha level of $p = 0.10$.

RESULTS

Descriptive Data

Table 1 displays the data for all participants for all variables ordered by VAS score.

Relationships Among Variables

Table 2 displays the Pearson correlations between all variables. The direction of the correlations was such that more pain was associated with higher levels of disability, greater iliopsoas muscle length, and less low back endurance. Scatter plots for the highlighted correlations with $p < 0.10$ are presented in **Figures 1** to **3**.

Differences Between Pain Groups

The results of the *t*-tests performed for all variables for all pain groups are shown in **Table 3**. A significant difference was found between pain groups for the Oswestry ($p < 0.000$ for pain-2 group, $p < 0.008$ for pain-5 group) and iliopsoas muscle length variables ($p < 0.045$ for pain-2 group, $p < 0.028$ for pain-5 group), regardless of which pain group was used. A significant difference was also detected for back extensor muscle strength ($p < 0.016$) and back extensor muscle endurance variables ($p < 0.068$) for the pain-5 group. The "painful" groups exhibited more disability, greater iliopsoas length, weaker back extensor muscles, and less back extensor muscle endurance than the "minimally painful" groups. For nonsignificant analyses, the power ranged from a low of 0.1483 for the pain-2 back endurance analysis to a high of 0.6579 for the pain-2 abdominal strength analysis.

Differences Between Amputation Levels

The results of the analyses for differences between individuals when grouped by amputation level can be found in **Table 4**. Differences between levels were found for back strength and back endurance, with individuals with transfemoral amputation having stronger back extensor muscles, but less back extensor muscle endurance than those with transtibial amputation. For nonsignificant analyses, the power ranged from a low of 0.4947 for the analysis of hamstring muscle length to a high of 0.9290 for the analysis of abdominal muscle strength.

Potential for Confounding Factors

We performed tests of differences (*t*-tests and ANOVA (analysis of variance) with Tukey post hoc analysis when appropriate) to determine whether four

Table 1.
Raw data for all participants ordered by visual analog scale (VAS) score.

Participant	Gender	Level	Age	Post-amputation (yr)	Cause	Use	Years of Use	Satisfaction*	Components	VAS Score	OSW	Bilateral Iliopsoas	SLRB	Abd-Str (1–5)	Back-Str (1–5)	Back-End (s)
4	W	TT	78	14.0	T	Cmty amb	13.5	2	Seattle	0.0	2.0	–1.5	–27.0	5	2	38
5	M	TT	56	12.0	D	High	12.0	3	Ceterus, 3S	0.0	2.2	–6.0	–37.0	2	4	52
7	W	TT	75	2.0	D	Cmty amb	1.5	2	FF, 3S	0.0	13.3	–22.0	–30.0	2	2	39
13	M	TT	69	3.0	D	Cmty amb	2.0	3	SL foot, 3S	0.0	0.0	–11.0	–23.0	4	3	34
10	M	TF	59	4.0	D	Cmty amb	3.5	3	Cleg	0.63	0.0	–24.0	–14.0	4	4	14
12	M	TF	37	12.0	D	High	12.0	3	Cleg	0.63	0.0	–20.0	–43.0	5	5	22
9	M	TT	67	5.0	D	Cmty amb	5.0	3	Luxon, 3S	0.75	0.0	–27.0	–35.0	4	2	37
8	M	TT	77	10.0	T	Cmty amb	10.0	2	FF, 3S	0.88	2.2	0.0	–38.0	4	2	40
11	M	TT	74	4.0	D	Cmty amb	4.0	3	CPI foot, SPSC	1.30	0.0	–11.5	–32.0	4	4	12
15	M	TF	49	33.0	T	High	33.0	3	Cleg	1.90	14.0	–17.0	–14.0	4	5	19
3	M	TF	50	3.0	D	—	3.0	—	—	2.50	22.0	–8.5	–40.0	5	5	15
18	M	TF	39	16.0	T	High	16.0	3	TK, SL	2.50	10.0	–11.0	–32.0	5	5	24
19	M	TT	45	3.5	D	High	3.5	3	FF	2.50	14.0	0.0	–10.5	4	2	27
6	M	TT	45	15.0	T	Cmty amb	15.0	3	VSP	3.10	28.0	–22.0	–34.0	5	4	66
17	M	TF	40	4.0	T	High	4.0	2	FF, 3R60	3.80	32.0	–17.5	–33.0	5	2	12
14	W	TT	38	18.0	T	High	17.0	3	VSP, 3S	5.00	30.0	0.0	–7.5	5	2	7
20	M	TF	51	31.0	T	Cmty amb	31.0	2	HK	6.30	36.0	–6.0	–17.0	5	3	25
1	M	TF	56	26.0	D	Cmty amb	26.0	3	FF	6.90	24.0	0.0	–54.0	3	2	22
16	M	TT	70	10.0	D	Limited	9.0	1	—	6.90	18.0	–1.0	–10.0	2	2	0

*The satisfaction rating ranges from 1 to 3, with "1" reporting frequent and major problems, "2" occasional discomfort or minor problems, and "3" no complaints.

AbdStr = abdominal muscle strength
BackStr = back extensor muscle strength
BackEnd = back extensor muscle endurance
CPI = College Park Industries (Fraser, MI) (foot)
Cmty amb = unrestricted community ambulation
D = disease
FF = flexfoot
High = exceeds community ambulation, runs, and athletics with prosthesis
HK = hydraulic knee (unknown type)
Limited = household ambulation, minimum community ambulation
M = man
OSW = Oswestry
T = Trauma
TF = transfemoral
3S = pin and lock suspension
SL = SpringLite (foot)
SLR = straight leg raise
SLRB = straight leg raise bilateral
SPSC = suprapatellar/supracondylar suspension
TK = total knee
TT = transtibial
VSP = Vertical Shock Pylon (foot)
W = woman

factors other than pain and amputation level may have influenced the results: activity level, recruitment method, years postamputation, and cause of amputation. For the activity level factor, we categorized participants as low-level prosthetic users, functional community ambulators, or high-demand prosthetic users based on the answer provided to a question regarding activity level. We classified them as low-level users if they ambulated minimally around the home and community. We classified them as functional community ambulators if they were able to negotiate the community with ease, but did not engage in higher-level function, such as running or athletics. We categorized participants as high-demand prosthetic users if they participated in athletics or other excessive activity. No significant differences were detected in any of the pain, functional, or physical measures based on activity level.

We categorized recruitment as being from support groups, prosthetists, or a golf outing. We noted a significant difference in Oswestry scores ($p < 0.010$) based on recruitment. Our post hoc analysis revealed a significant difference ($p < 0.038$) between those recruited from the prosthetist and those recruited from the support group and between those from the prosthetist and those from the golf outing ($p < 0.009$). Interestingly, all participants recruited from the prosthetist scored a 0 on the Oswestry, indicating no functional limitations. A significant difference was also found in iliopsoas muscle length based on recruitment ($p < 0.027$), with post hoc analysis showing that those recruited from the support group had significantly

Table 2.
Pearson correlations significance (2-tailed) of main variables.

Test	VAS Score	Oswestry	IPB	SLRB	AbdStr	BackStr	BackEnd
VAS	1.000	—	—	—	—	—	—
	—	—	—	—	—	—	—
Oswestry	0.769	1.000	—	—	—	—	—
	0.000	—	—	—	—	—	—
IPB	0.397	0.307	—	—	—	—	—
	0.092	0.200	1.000	—	—	—	—
SLRB	0.163	0.152	0.107	1.000	—	—	—
	0.506	0.535	0.664	—	—	—	—
AbdStr	0.023	0.229	–0.034	0.010	1.000	—	—
	0.926	0.345	0.891	0.968	—	—	—
BackStr	–0.231	–0.184	0.320	0.159	0.280	1.000	—
	0.342	0.451	0.182	0.516	0.246	—	—
BackEnd	0.482	0.191	–0.028	–0.361	–0.068	0.006	1.000
	0.037	0.433	0.910	0.129	0.781	0.980	—

AbdStr = abdominal muscle strength; BackEnd = back extensor muscle endurance; SLRB = straight leg raise bilateral; BackStr = back extensor muscle strength; IPB = iliopsoas bilateral; VAS = visual analog scale

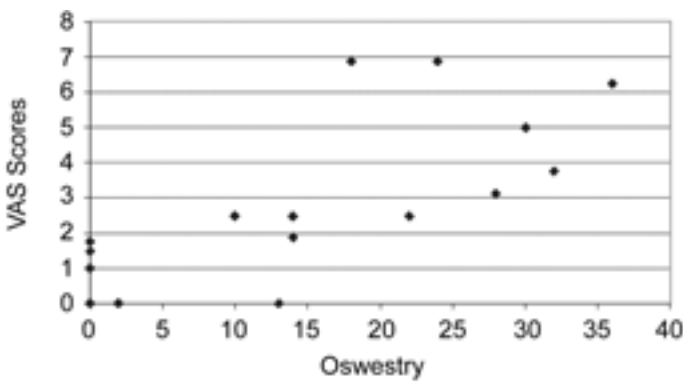

Figure 1.
Scatter plot for visual analog scale (VAS) against Oswestry scores. Pearson correlation = 0.769 and significance = 0.000.

more iliopsoas muscle length ($p < 0.023$) as compared to those recruited from the prosthetists.

We then categorized participants into two groups for years since amputation: those ≤5 years postamputation and those having the amputation performed >5 years prior. A *t*-test revealed a significant difference ($p < 0.032$) in length of the iliopsoas muscle based on years postamputation, with those participants having the amputation performed >5 years ago demonstrating greater iliopsoas muscle length than those with amputations of 5 years or less.

We found a significant difference ($p < 0.014$) in abdominal strength based on cause of the amputation. People with amputation because of trauma exhibited greater abdominal strength than those with amputations because of disease processes. No differences existed in the other variables when analyzed by cause of amputation.

DISCUSSION

For this study, we investigated measures related to LBP in a sample of people with LLA. While the incidence of LBP in this population has been studied, physical measures associated with this phenomenon have not. Ehde et al. [35], in a study on back pain as a disabling factor in persons with LLA, found that 43 percent of participants experienced mild pain (VAS 1–4), 25 percent reported moderate pain (VAS 5–6), and 25 percent reported severe pain with a VAS score of ≥7. Using that classification for our data, we find that 80 percent of participants reported minimal pain, 5 percent reported moderate levels of pain, and 15 percent reported severe LBP. A number of reasons could explain why our demographics may differ from

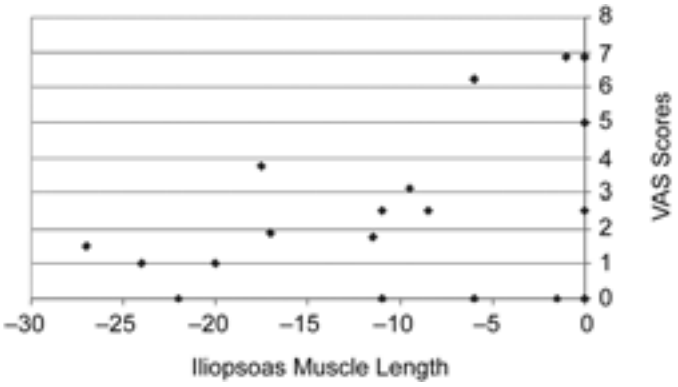

Figure 2.
Scatter plot for visual analog scale (VAS) against bilateral iliopsoas muscle length. Pearson correlation = 0.397 and significance = 0.092.

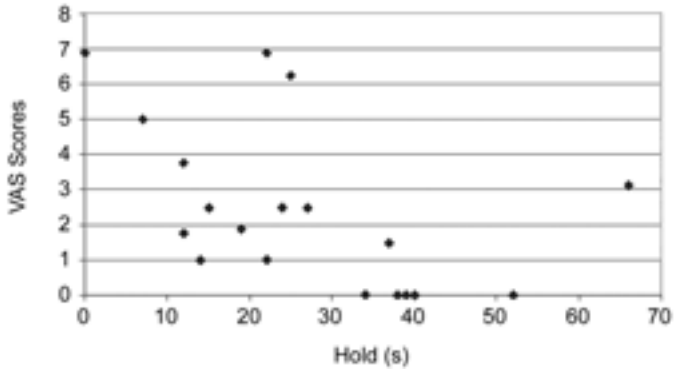

Figure 3.
Scatter plot for Visual Analog Scale (VAS) against back extensor muscle endurance. Pearson correlation = –0.482 and significance = 0.037.

Table 3.
Independent *t*-tests for all variables grouped by pain level.

Variable	Minimal Pain Group (Mean ± SD)	Painful Group (Mean ± SD)	*t*-Test	*p*-Value
Oswestry				
Pain-2	3.37 ± 5.51	23.80 ± 8.63	–6.214	0.000
Pain-5	9.31 ± 10.93	27.00 ± 7.75	–3.010	0.008
IPB				
Pain-2	–4.00 ± 9.48	–5.94 ± 6.21	–2.162	0.045
Pain-5	–12.43 ± 8.62	–1.75 ± 2.87	–2.398	0.028
SLRB				
Pain-2	–29.30 ± 9.87	–26.44 ± 15.99	–0.474	0.642
Pain-5	–29.50 ± 9.95	–22.12 ± 21.62	–1.023	0.321
AbdStr				
Pain-2	3.80 ± 1.03	4.33 ± 1.12	–1.081	0.295
Pain-5	4.13 ± 0.99	3.75 ± 1.50	0.621	0.543
BackStr				
Pain-2	3.30 ± 1.25	3.00 ± 1.32	0.508	0.618
Pain-5	3.40 ± 1.30	2.25 ± 0.50	2.750	0.016
BackEnd				
Pain-2	30.70 ± 13.14	22.00 ± 18.81	1.179	0.255
Pain-5	30.07 ± 15.70	13.50 ± 11.96	1.949	0.068

Pain-2 grouping by visual analog scale (VAS) score < 2.00
Pain-5 grouping by VAS score ≤ 4.99
AbdStr = abdominal muscle strength
BackStr = back extensor muscle strength
BackEnd = back extensor muscle endurance
IPB = iliopsoas bilateral
SLRB = straight leg raise bilateral
SD = standard deviation

previously published reports. Ehde et al.'s study used hospital-based databases for recruitment with minimum time postamputation of 6 months, whereas we recruited from different sources with a minimum of 18 months postambulation after the amputation. Recruitment was shown to be a confounding variable for pain with those recruited from the prosthetist having less pain and those in the golf outing having the most pain. Perhaps those participants in close contact with their prosthetist have a better-fitting socket and fewer difficulties, and those playing golf have more stress placed on the back and thus higher levels of pain. This lower level of pain would explain the lack of functional limitations because of LBP in those recruited from the prosthetist. Additionally, certain individuals reported severe back pain and chose not to participate for fear that participation might exacerbate their pain. Increased pain was also associated with greater iliopsoas muscle length and participants with an amputation of longer than 5 years had greater iliopsoas muscle length as compared to those with amputations of less than 5 years ago. Perhaps a gradual but continuous change occurs in mechanics and/or degradation of structures, leading to pain. Finally, an interesting finding was that everyone in the pain-5 group was a prosthetic user longer than 72 months. Although years of use were not significantly related to pain levels, this should be further investigated.

Oswestry

Our results revealed an association between LBP and functional scores as measured by the Oswestry. In addition, we found significant differences in self-perceived functional limitations in people with LBP as compared with those without LBP. Although clinicians may attribute

Table 4.
Independent *t*-tests for all variables grouped by amputation level.

Variable	Transtibial Group (n = 11) (Mean ± SD)	Transfemoral Group (n = 8) (Mean ± SD)	*t*-Test	*p*-Value
VAS Score	1.88 ± 2.33	3.22 ± 2.25	–1.25	0.230
Oswestry	9.97 ± 11.40	17.25 ± 13.60	–1.27	0.222
IPB	–8.13 ± 9.31	–13.00 ± 8.00	1.19	0.251
SLRB	–25.81 ± 1.44	–30.88 ± 14.79	0.84	0.412
AbdStr	3.73 ± 1.19	4.50 ± 0.76	–1.61	0.126
BackStr	2.64 ± 0.92	3.88 ± 1.36	–2.38	0.030
BackEnd	32.00 ± 19.51	19.13 ± 4.91	2.10	0.058

AbdStr = abdominal muscle strength
BackStr = back extensor muscle strength
BackEnd = back extensor muscle endurance
IPB = iliopsoas bilateral
SD = standard deviation
SLRB = straight leg raise bilateral
VAS = visual analog scale

functional difficulties in this population to problems with the amputation and the prosthesis, we suggest that clinicians working with patients after amputation also consider LBP as a possible explanation for limitations in daily activities.

Physical Measures

We selected the five physical measures for this study based on literature linking them to LBP in the general population. For three of the measures (iliopsoas length and back extensor muscle strength and endurance), our results supported this link. For the other two measures (abdominal muscle strength and hamstring muscle length), our results did not support this link.

Iliopsoas Muscle Length

Research has shown that optimal extensibility of iliopsoas is needed to prevent LBP [22]. A tight iliopsoas may contribute to a lack of hip extension during the heel-off and toe-off phases of gait, decreasing stride length. To compensate, the pelvis may rotate anteriorly, hyperextending the spine [36] to increase stride length [7]. This may lead to microtrauma of the sacroiliac joints and lumbar spine, possibly leading to hypermobility in the lumbar spine and resultant LBP [37]. Additionally, an anterior pelvic tilt, caused by tightness in the iliopsoas muscle group, may cause greater posterior compressive forces in the lumbar spine [38], leading to discogenic pain. Surprisingly, those participants with LBP demonstrated greater iliopsoas muscle length than those without LBP, and a number of possible explanations exist for this unexpected finding.

Flat backs, or those classified as being in a posterior tilt, have been associated with increased pain secondary to a hypothesized decrease in clinical stability [39–40]. Although we did not assess posture directly, perhaps the increased range of motion seen at the hip in the Thomas test position in the group with pain was associated with a posterior pelvic tilt posture, contributing to increased pain from instability. In addition, a swayback posture, seen with increased hip flexor flexibility and subsequent posterior pelvic tilt, places the posterior spinal structures under tension, which may be associated with neurological dysfunctions, deformity, and incapacitating pain [39–40]. People with a transfemoral amputation, and who use a quadrilateral socket, have pressure placed against Scarpa's triangle to help maintain the pelvis against the posterior brim for weightbearing. This pressure against the anterior aspect of the pelvis has the potential to place the pelvis in a posterior tilt. Another possible theory has been proposed by Dannenberg, who stated that a lack of iliopsoas stability at its proximal insertion leads to difficulty initiating swing phase in gait with a subsequent need to compensate via hip-hiking or some other mechanism [23]. This repetitive strain to the low back region with each step could cause LBP.

Back Extensor Muscle Strength

In general, back extensor muscles are responsible for proper posture of the lumbar spine, maintaining the back in a position of slight lordosis [41], controlling the rate and magnitude of flexion, and attenuating ground reaction forces. One study found a significant relationship between weakness of the back extensors and first-time experience of LBP in men [3].

We found a significant difference in back strength in individuals with pain as compared to those without in the pain-5 group, consistent with Panjabi's hypothesis that weakness in the back stabilizers leads to increases in the size of the neutral zone and spinal instability [39–40]. This neutral zone, as defined by Panjabi [40], is a "region of intervertebral motion around the neutral posture where little resistance is offered by the passive spinal column." Failure to maintain the neutral zone is due to failure of the muscles, since the ligaments have a supporting role only at end range. A decrease in multifidus strength, a muscle included in the local muscle system, could be implicated in clinical

instability and pain [42]. It has been noted that multifidus is active when the trunk is extended or hyperextended from the prone position [41], as was used in this study.

Back Extensor Muscle Endurance

In numerous studies, a decrease in back extensor muscle endurance has been associated with LBP [3–4,32,43]. In addition, studies have also shown that multifidus has a significantly higher fatigue rate in participants with LBP as compared with those without LBP [42]. When these muscles are fatigued, researchers have hypothesized that changes in intersegmental motion around the neutral zone can lead to spinal instability [39–40].

One recent report suggested that a decrease in back endurance had the highest association with LBP [43]. In our study, individuals with greater levels of pain had significantly less back extensor muscle endurance as compared with those without pain. Normative holding time for healthy participants has been reported to be approximately 3 min [32–33]. Our study participants had an average holding time of only 26.5 s, with a maximum of 66 s in a participant with a VAS of 3.

Researchers have hypothesized that people with poor back extensor muscle endurance have a low fatigue threshold [44], which may predispose them to back injury by stressing the passive supporting structures [4,44]. Why persons with amputation exhibit lower holding times is unknown. One theory suggests that a generalized decreased activity level leads to lowered endurance of these postural muscles. Another plausible reason may be changes in gait patterns of the person with an LLA, particularly the decreased stride length up to two SDs below that of persons without amputation [19–20]. With a decreased stride length, the back extensor muscles may play less of a role in gait and thus have a lower endurance. Further study is warranted to determine which of these factors comes first, the decreased stride length or the weakness of the back extensors. Additionally, one study found hyperactivity of the hip extensors during the early and midstance phases of gait for participants with a transtibial amputation [18]. This increased activity may aid the hip extensors in assuming the role of stabilization and somehow decrease the need of the back extensors to stabilize the pelvic/low back region during ambulation. Similarly, Winter has noted that the hip muscles play a role in performing fine postural adjustments of the trunk [45]. Therefore, if the hip muscles are hyperactive, this may decrease the endurance of the back extensors. As previously mentioned, perhaps a swayback posture from hip hyperextension, and relying on connective tissue for end-range control, places less of a demand on the back extensor musculature.

Abdominal Muscle Strength and Hamstring Muscle Length

It has been theorized that hamstring length is a critical component for maintenance of proper lumbar curvature. Tightness in the hamstring muscles can pull the pelvis into a posterior tilt, decreasing the lordosis of the lumbar spine, leading to poor attenuation of forces and an increase in anterior compression forces of the lumbar spine [46]. Hamstring tightness may ultimately lead to discogenic pain secondary to elevated flexion forces. That was our primary reason for including this variable in our study. Conversely, weakness of the abdominal muscles is thought to contribute to an anterior pelvic tilt with lumbar hyperlordosis and the possibility of LBP.

However, many conflicting studies address the role of the abdominals and hamstrings in the presence of LBP [2–3,5,7,21–22,43,47]. Our lack of significant findings for these two variables is not surprising, given the lack of consensus on the role of the abdominals and hamstrings by previous researchers.

Comparison Between Levels of Amputation

Participants with transfemoral amputation reported more pain, had greater functional limitations, and displayed shorter iliopsoas muscles than those with transtibial amputation, but these apparent differences were not statistically significant. However, we reported significant differences in back extensor muscle strength and endurance between the two groups, with people with transfemoral amputation exhibiting greater strength but less endurance than those with transtibial amputation. In general, individuals with a transfemoral amputation have lower levels of activity than people with transtibial amputation, and this may explain the differences in back extensor muscle endurance between the two groups. With respect to back extensor muscle strength, the back extension and hip-hiking used to advance the limb during gait with a transfemoral prosthesis may explain the greater strength of these muscles in those with transfemoral compared with transtibial amputation.

Limitations

The primary limitation of the study was the number of participants recruited, which limited our power to detect differences between groups. Many of the tests of differences in this study had power of less than 60 percent. A sample size of 30 to 60 participants would have given us sufficient power for the majority of measures. In addition, the simple clinical measures we used may have limited our ability to detect subtle differences between groups.

Future Research

We recommend that future investigations on the influence of physical measures on LBP in people with LLA use a larger sample size. Additionally, because of the possibility that recruitment methods may have influenced our results, alternate sampling methods should be considered.

Having found that several physical factors appear to be related to LBP in people with LLA, we suggest an intervention study be undertaken to address the rehabilitation of persons with LLA and LBP who have altered iliopsoas muscle length, back extensor muscle strength, or back extensor muscle endurance. In addition, conducting a prevention study would be useful to target individuals with recent LLA who may not yet be experiencing LBP.

Because many of the impairments found in this study have the potential to impact gait, a study is under way to determine if a difference can be found in gait parameters in people with transtibial amputation with LBP as compared with those without LBP.

CONCLUSION

Higher levels of LBP were associated with increased iliopsoas muscle length, decreased back extensor muscle strength, and decreased back extensor muscle endurance in individuals with LLA. Clinicians who work with patients with amputation who have LBP may want to consider the role that these physical measures may play in the presence of LBP. Further research needs to be undertaken to fully understand the development of and treatment for LBP in persons with LLA.

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