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Original Research

Frequency and Circumstances of Falls Reported by Ambulatory Unilateral Lower Limb Prosthesis Users: A Secondary Analysis

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Abstract

Background: More than 50% of lower limb prosthesis (LLP) users report falling at least once a year, placing them at high risk for adverse health outcomes such as decreased mobility and diminished quality of life. Efforts to decrease falls in LLP users have traditionally focused on developing clinical tests to assess fall risk, designing prosthetic components to improve patient safety, and identifying risk factors to recognize potential fallers. Little attention has been directed toward recording, reporting, and characterizing the circumstances of falls in LLP users. Identifying the most common types of falls could help guide and prioritize clinical and research needs.
Objective: To characterize the frequency and circumstances of falls reported by unilateral LLP users.
Design: Secondary analysis of data from 2 cross-sectional studies.
Setting: Outpatient clinic and research laboratory.
Participants: Ambulatory unilateral transtibial and transfemoral LLP users (N = 66).
Intervention: None.
Outcome: A fall-type classification framework was developed based on biomechanical theory and published falls terminology. Self-reported falls and accompanying narrative descriptions of LLP users' falls in the previous 12 months were analyzed with the framework. Frequencies, estimated proportions, and estimated counts were compared across fall circumstances using 95% confidence intervals.
Results: Thirty-eight participants (57.6%) reported 90 falls during the previous year. All reported falls were successfully categorized using the proposed framework. Most falls occurred from disruptions to the base of support, intrinsic destabilizing factors, and a diverse set of fall patterns. Walking on level terrain was the most common activity at the time of a fall.
Conclusion: This secondary analysis showed that falls remain frequent in ambulatory LLP users and that clinicians and researchers might wish to prioritize falls owing to disruptions of the base of support that occur while walking. Additional research with a larger sample is required to confirm and expand these results.
Level of Evidence: III

Introduction

More than 50% of lower limb prosthesis (LLP) users report falling at least once a year [1-5], placing them at high risk for adverse health outcomes such as decreased mobility and diminished quality of life [3,6,7]. Attempts to lower the prevalence of falls in LLP users have traditionally focused on developing and validating clinical tests to assess fall risk [8-12], designing and testing prosthetic components to improve patient safety [13-16], characterizing the biomechanics of key balance strategies to identify deficits in those at risk for falls [17-23], and identifying risk factors to help recognize potential fallers [2,5,7,24,25]. However, little attention has been directed toward recording, reporting, and characterizing the circumstances of falls in LLP users [1,4,7]. For example, are falls caused primarily by external factors imposed by the environment or are falls initiated by internal physiologic factors? Are LLP users more susceptible to trips, slips, or prosthetic failures? What activities are LLP users most commonly engaged in at the time of a fall? Answers to these questions could help direct treatment to the most prevalent and consequential types of falls [26-29], prioritize research needs in areas related to fall assessment (eg, screening methods and diagnostic tests) [30], and generate

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evidence to develop and revise reimbursement policies (eg, prosthetic components that decrease falls). Therefore, the primary objective of this project was to provide an initial characterization of the circumstances of falls in ambulatory unilateral LLP users.

The characterization of fall-related circumstances in LLP users is limited by the lack of a universal fall-type classification framework and taxonomy suited to LLP users. The use of incomplete and study-specific terminology [1,4] has limited comparisons between studies and prevented a more comprehensive characterization of fall circumstances in LLP users. Several classification frameworks have been used to characterize falls in older adults [26,31,32], but they are not entirely applicable to the experiences of LLP users [33]. A fall-type classification framework for LLP users would provide a structured approach to soliciting, recording, reporting, and studying falls experienced by LLP users. Therefore, a secondary objective of this project was to propose and evaluate an LLP user-specific fall-type classification framework and taxonomy.

Methods

Study Design

A secondary analysis of self-report falls data collected in 2 previous studies [11,12] was conducted to address the study objectives. Data were combined owing to similar study instruments, data collection methods, and participants. The 2 studies sought to evaluate the validity of clinical balance tests in ambulatory LLP users. No a priori power analysis was performed for this secondary analysis. Original study protocols were reviewed and approved by institutional review boards at the University of Illinois at Chicago and Northwestern University. All individuals provided written informed consent before participation.

Participants

Participants who met the following inclusion and exclusion criteria were selected from the datasets in the 2 studies [11,12]: age at least 18 years; unilateral, transtibial, or transfemoral amputation; at least 1 year since amputation; and able to walk with or without an assistive device. Exclusion criteria included congenital or upper extremity limb loss and comorbidities limiting mobility (eg, knee replacement, severe pulmonary disease, ulcers).

Measurements

Participant Demographics, Prosthetic-related Information, and Retrospective Falls Data

Data on age, gender, amputation level, cause of amputation, and time since amputation were collected by interview with a study investigator. Study investigators also measured height and weight. To assess fall history, each participant was asked, "In the past 12 months have you had any falls including a slip or trip in which you inadvertently lost your balance and landed on the ground or lower level?" [34]. Participants reporting a fall were asked to provide a narrative description of the event (ie, circumstances of their fall[s]) [29,31].

Development of Fall-type Classification Framework and Taxonomy

A fall-type classification framework and taxonomy was developed based on biomechanical theory, published terminology, and fall descriptions reported by or observed among LLP users [1,4,33] and older adults [26,27,29,31,35-38]. Fall circumstances reported by older adults were referenced when developing the framework to supplement the limited reporting of fall circumstances in LLP users.

The fall-type classification framework (Figure 1) is a 3-level hierarchical system describing the location of

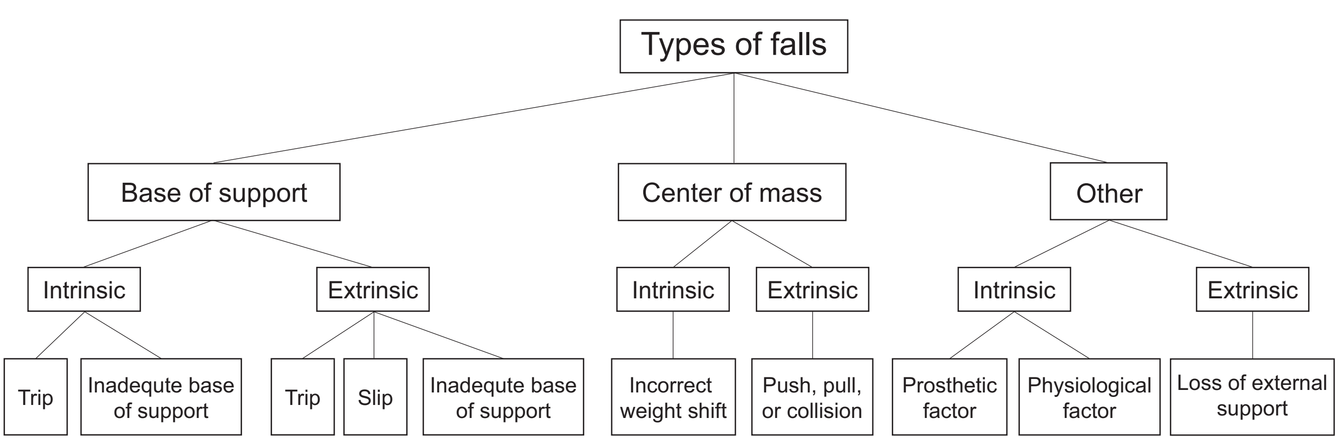

Figure 1. Fall-type classification framework. The proposed framework is a 3-level hierarchical system that characterizes falls based on the location of the destabilizing force (level 1), the source of the destabilizing force (level 2), and the fall pattern (level 3).

the destabilizing force, the source of the destabilization, and the ensuing fall pattern. The first level of the framework characterizes the location of the destabilization with respect to the body. First-level descriptors are based on a simple biomechanical model in which falling results from uncorrected disruptions between the base of support (BoS) and the center of mass (CoM) [27,29,39-42]. Disruption can occur from a destabilizing force acting to displace the BoS (ie, feet) from beneath the CoM (ie, a BoS fall) or displace the CoM (ie, body) beyond its existing BoS (ie, a CoM fall) [4,27,29,33,36]. Falls with no apparent biomechanical disruption between the BoS and the CoM are classified as "other" types of falls [27]. Characterizing the most common location of destabilizing forces leading to a fall could help determine the most suitable targets for mitigating fall risk through balance training, clinical balance assessment, and/or prosthetic design [1,28].

The second level of the framework characterizes the source of destabilization. A destabilizing force that acts on the CoM or BoS can originate from intrinsic or extrinsic sources. Intrinsic sources are personal factors, often physiologic in nature (eg, muscle weakness). Extrinsic sources are external factors imposed by the environment that result in unexpected disruptions (eg, icy walkway, being bumped by someone) [1,29,31,35,43]. Categorizing falls as intrinsic or extrinsic can guide clinical decision making in several ways. First, it can highlight potential preventative strategies. Falls attributed to extrinsic sources are often addressed through patient education and/or environmental modifications [44-46]. Falls attributed to intrinsic sources might require interventions that target specific neuromusculoskeletal deficits. Second, individuals who experience falls from intrinsic sources are more likely to fall again because such sources often indicate systemic issues [47]. Thus, categorizing falls as intrinsic or extrinsic could help identify individuals who are likely to be recurrent fallers. Third, contemporary clinical balance tests largely probe intrinsic over extrinsic factors. If most falls experienced by LLP users are attributed to extrinsic sources of destabilization, then clinically feasible tests that replicate such extrinsic sources of destabilization might need to be developed.

The third level of the framework describes fall patterns [1,20,28]. For example, a destabilizing force acting on the BoS from an extrinsic source can produce a fall from a trip, a slip, or an inadequate BoS [26]. This level of the framework also includes prosthetic-related factors (eg, prosthetic knee buckling) [1], physiologic factors (eg, collapse from muscle weakness), and loss of external support (eg, support structure or assistive device moving unexpectedly) [26,31]. Characterizing fall patterns could be important for selecting treatment and preventative strategies with a level of specificity that is needed for balance training, yet beyond what is offered by the first 2 levels of the framework [28,48-51]. If certain fall patterns are more prevalent, then resources should be directed toward their investigation. Inclusion of fall patterns within the framework also introduces terminology consistent with that used by clinicians and patients. A complete set of definitions and examples for each component of the fall-type classification framework is provided in Appendix 1.

Classifying Falls

Two reviewers independently classified each reported fall using the fall-type framework. Participants' narrative descriptions of fall events were analyzed to determine whether the BoS or CoM was disrupted (level 1). If participants described neither, then the fall was assigned to "other." Each type of level 1 fall was further characterized based on whether participants described extrinsic (ie, environmental) or intrinsic (ie, personal) factors as the source of the destabilization (level 2). If intrinsic and extrinsic factors were reported, then the source was categorized as intrinsic [31]. Falls were subsequently classified with greater detail based on reported movements during the fall (level 3). For example, if a participant reported catching his or her foot in a crack in the sidewalk and fell forward, then the fall was classified as a BoS extrinsic trip.

In addition to fall type, activity at the time of the fall was categorized. The same 2 reviewers extracted details of the specific form of activity at the time of the fall from the narrative description provided by each participant. Previously reported activities at the time of a fall (eg, walking, transfer, reaching) [7,26,33,36] were used as an initial guideline for categorization. Falls were classified as "unknown" when participants could not recall the events concerning the fall.

Statistical Analysis

For each fall type and activity at the time of a fall, we tabulated the total number of reported falls (ie, frequency), the proportion of participants falling at least once (ie, estimated proportion), and the average number of falls per participant (ie, estimated count). Frequencies were expressed as a number and a percentage of all reported falls. Estimated proportions were calculated as the ratio of participants who reported at least 1 fall for each type or activity with respect to all participants, multiplied by 100. Estimated counts were calculated as the ratio of all falls reported for each type or activity with respect to the total number of participants. To determine whether there were any differences in the estimated proportions or counts across the various types of falls and activities at the time of a fall, 95% confidence intervals (CIs) were computed from a t-distribution and compared across fall types and activities. Overlap between 95% CIs was taken as a conservative estimate of no significant difference.

All statistical analyses were performed using SPSS 24 (SPSS, Inc, Chicago, IL).

We also sought to ascertain the ability of the proposed fall-type classification framework to accurately capture the range of fall types reported by LLP users. To that end, after classification, the framework was reviewed for (1) categories that did not align with any reported fall events, which would suggest they might be unnecessary and could be removed, and (2) falls that did not fit into the framework, which would suggest that additional categories might be required.

Results

Participants

Records of 70 LLP users who participated in the original studies [11,12] were reviewed. Three participants were excluded because of amputation level (2 bilateral; 1 ankle disarticulation), and the fourth participant was excluded because time since amputation was less than 1 year. Data from 66 participants were included (Table 1).

Fall Prevalence

Sixty-six participants reported a total of 90 falls (ie, 1.36 falls per participant). Thirty-eight participants (57.6%) reported at least 1 fall in the past 12 months. Fourteen participants (22.1%) reported 1 fall, 9 (13.6%) reported 2 falls, and 15 (22.7%) reported at least 3 falls in the past 12 months. Based on the narrative description provided by the participants of their fall(s) and activities at the time of their falls, all reported falls were considered to have occurred while wearing the prosthesis.

Suitability of Fall-type Classification Framework

Eight falls (9%) were categorized as "unknown" (Figure 2), 7 owing to incomplete data collection forms and 1 owing to a participant's inability to recall the specific circumstances of a fall. Three framework categories did not align with at least 1 reported fall event: "a loss of external support," "push, pull, or collision," and "inadequate base of support."

BoS vs CoM Falls

The BoS was the most commonly reported location of a destabilizing force leading to a fall, accounting for 54% (49 of 90) of all reported falls (Figure 2). The proportion of participants (36.4%, 95% CI 26.4-48.4) and the average number of falls per participant (0.75, 95% CI 0.63-0.85) owing to disruption of the BoS were significantly larger than those arising from disruption of the CoM (proportion 9.1%, 95% CI 1.9-16.3; average number per participant 0.18, 95% CI 0.09-0.28) or those with no apparent disruption to the BoS or CoM (ie, "other"; proportion 16.7%, 95% CI 7.4-26.0; average number per participant 0.32, 95% CI 0.20-0.43; Table 2).

Intrinsic vs Extrinsic Falls

Intrinsic (ie, personal) factors were the most commonly reported source of destabilizing forces leading to a fall (Figure 2). Fifty-two of the 90 reported falls (58%) were attributed to intrinsic sources (eg, missed step, poor foot clearance), whereas 30 of the reported falls (33%) were attributed to extrinsic sources (eg, icy surface, cracked sidewalk, uneven terrain; Figure 2). However, neither the proportion of participants reporting a fall nor the average number of falls per participant was significantly different between intrinsic and extrinsic sources (Table 2).

Fall Patterns

Slips were the most commonly reported fall pattern, accounting for 23 of the 90 reported falls (26%). This was followed by trips and prosthetic factors, each accounting for 22% of all reported falls (Figure 2). The proportion of participants reporting slips (18.2%, 95% CI 8.6-27.8) and trips (16.7%, 95% CI 7.4-26.0) and the average number of slips (0.35, 95% CI 0.23-0.47) and trips (0.30, 95% CI 0.19-0.42) per participant were significantly larger than the proportion of participants reporting falls from physiologic factors (1.5%, 95% CI 0-4.6) and the

Table 1
Sociodemographic and amputation-related characteristics

	Age (y)	Height (cm)	Weight (kg)	Time Since Amputation (y)	Gender	Amputation Level	Amputation Etiology
Mean	50.6	173	81.6	16.3	37 men 29 women	36 transtibial 30 transfemoral	39 trauma 13 dysvascular 5 cancer 7 infections 2 congenital
SD	14.1	8.65	16.9	13.0			
Range	21-76	155-189	104-266	1.6-57			

SD = standard deviation.

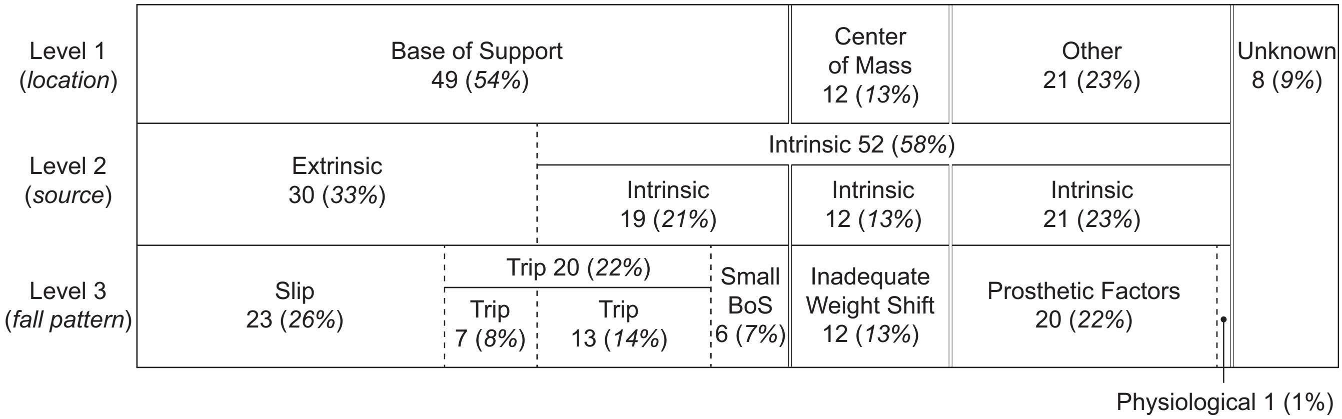

Figure 2. Number and frequency of fall types in lower limb prosthesis users as categorized by the classification framework. Base of support was the most common location of a destabilizing force resulting in a fall (level 1). Intrinsic factors were the most common source of a destabilizing force resulting in a fall (level 2). Slip, trips, and prosthetic factors accounted for nearly three-fourths of reported fall patterns (level 3).

number of falls per participant from physiologic factors (0.02, 95% CI 0-0.05) or an inadequate BoS (0.09, 95% CI 0-0.16). No other significant differences in the proportion of participants falling or number of falls per participant were identified across fall patterns (Table 2).

Activities Performed at the Time of a Fall

Participants most commonly reported walking on a level terrain when they experienced a fall. Falls that occurred while participants were walking on a level terrain accounted for 45.6% (41 of 90) of all falls (Figure 3). The proportion of participants who reported falling while walking on a level terrain (31.8%, 95% CI 20.2-43.4) and the mean number of falls while walking per participant (0.62, 95% CI 0.50-0.74) were significantly larger than falls that occurred while participants' were engaged in any other reported activity (eg, walking on an uneven terrain, stairs, transfers; Table 3). Thirteen (14%) falls occurred during an "unknown" activity (Figure 3).

Discussion

This secondary analysis was conducted to provide an initial characterization of the circumstances of falls in ambulatory unilateral LLP users and propose a fall-type classification framework. The prevalence of falls in this sample of LLP users exceeded 50%. Most of these falls occurred from disruptions to the BoS, intrinsic destabilizing factors, and a diverse set of fall patterns (eg, slips, trips, inadequate weight shift). Although additional work is necessary to confirm and expand these results in a larger sample, the present findings

Table 2
Proportion of participants who fell at least once and average number of falls per participant from various fall types*

	Proportion of Participants Who Fell		Number of Falls per Participant	
	Estimated Proportion, % (SE)	95% CI	Estimated Count, n (SE)	95% CI
Location of destabilizing force				
Base of support	36.4 (5.9)	26.4-48.4	0.75 (0.05)	0.63-0.85
Center of mass	9.1 (3.5)	1.9-16.3	0.18 (0.05)	0.09-0.28
Other	16.7 (4.6)	7.4-26.0	0.32 (0.06)	0.20-0.43
Source of destabilizing force				
Extrinsic	27.3 (5.5)	16.2-38.4	0.46 (0.06)	0.33-0.58
Intrinsic	39.4 (6.0)	27.2-51.6	0.78 (0.05)	0.69-0.89
Fall pattern				
Slip	18.2 (4.7)	8.6-27.8	0.35 (0.06)	0.23-0.47
Trip	16.7 (4.6)	7.4-26.0	0.30 (0.06)	0.19-0.42
Inadequate weight shift	9.1 (3.5)	1.9-16.3	0.18 (0.05)	0.09-0.28
Inadequate base of support	7.6 (3.3)	0-14.2	0.09 (0.04)	0-0.16
Prosthetic factors	15.2 (4.4)	6.2-24.1	0.30 (0.06)	0.19-0.42
Physiologic factors	1.5 (1.5)	0-4.6	0.02 (0.02)	0-0.05
Unknown	10.6 (3.8)	2.9-18.3	0.12 (0.04)	0.04-0.20

SE = standard error; CI = confidence interval.
* Estimated proportions and counts might not sum across fall types to 100% or 1.0, respectively, because participants can have more than 1 fall type if they reported multiple falls.

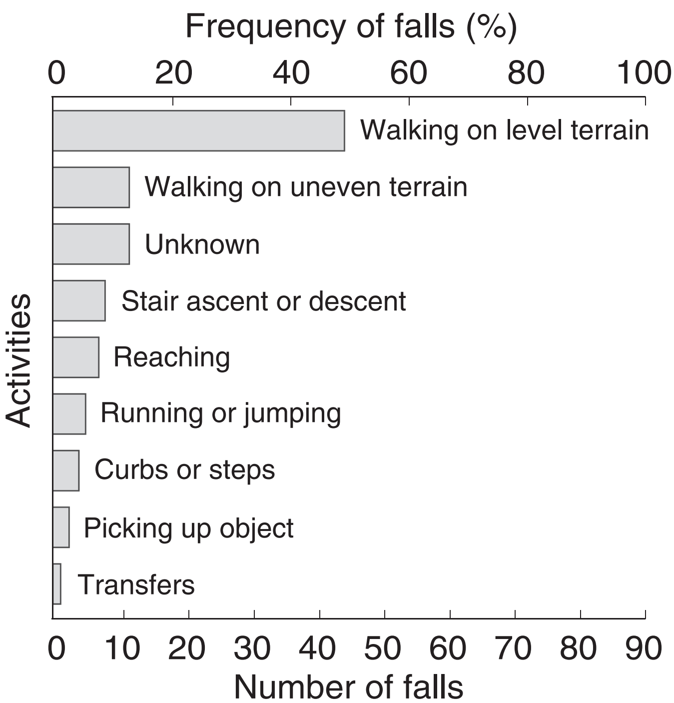

Figure 3. Number and frequency of falls reported by lower limb prosthesis users based on the activity at the time of a fall. Walking was the most commonly reported activity at the time of a fall. More falls occurred while walking on level vs uneven terrain.

represent an important first step in developing specific targets for clinical assessment and treatment and future research directions.

Proposed Classification Framework Successfully Categorized Fall Types Reported by LLP Users

The proposed framework offers 3 advantages. First, the 2 reviewers independently arrived at and agreed on the fall categorizations, suggesting that the framework and accompanying taxonomy are reliable. Second, the taxonomy appears comprehensive. All reported falls were successfully categorized. Only 8 (9%) of the reported falls were categorized as "unknown," well below 19% in older adults [52]. Third, 3 fall patterns, "push, pull, or collision," "loss of external support," and "inadequate base of support," were not used. These fall patterns have been previously reported by LLP users [4] and older adults [26]; as such, their removal from the framework is not recommended until they can be assessed in a larger sample.

Falls Remain Frequent in LLP Users

Historically, more than 50% of LLP users report falling at least once a year [1,2,4,5,25]. The results of this secondary analysis showed that the prevalence of falls in community-living ambulatory LLP users remains high, at 57.6%. The prevalence of recurrent falls, 36.3%, also remains at or above historically reported values for LLP users (ie, 23.4%-39.0%) [1,3,5]. The relevance of the increased frequency of falls in LLP users should be judged not only on its magnitude alone but also on the severity and occurrence of adverse outcomes. Between 8.0% and 57.0% of LLP users report a fall-related injury [1,4,7,25,53]; 14.6% seek medical attention and 7.3% require surgery [53] after a fall. Coupled with the importance LLP users place on balance [54], these consequences indicate that falls negatively affect the lives of a substantial portion of LLP users. Research exploring new approaches guided by the types of falls experienced by LLP users might be needed to decrease falls in LLP users.

LLP Users Are More Susceptible to BoS Than CoM Falls

BoS falls are more common than CoM falls in LLP users. These findings are consistent with those in older adults without lower limb amputation, in whom BoS falls consistently outnumber CoM falls [27,31,36-38].

Table 3
Proportion of participants who fell at least once and average number of falls per participant for activities reported at the time of a fall*

	Proportion of Participants Who Fell		Number of Falls per Participant	
	Estimated Proportion, % (SE)	95% CI	Estimated Count, n (SE)	95% CI
Walking on level terrain	31.8 (5.7)	20.2-43.4	0.62 (0.06)	0.50-0.74
Unknown	12.1 (4.0)	4.0-20.3	0.20 (0.05)	0.10-0.30
Stairs	10.6 (3.8)	2.9-18.3	0.11 (0.04)	0.03-0.18
Walking on uneven terrain	9.1 (3.5)	1.9-16.3	0.20 (0.05)	0.10-0.30
Running or jumping	6.1 (2.9)	0.1-12.0	0.06 (0.03)	0-0.12
Reaching	6.1 (2.9)	0-12.0	0.09 (0.04)	0.02-0.16
Curbs or steps	3.0 (2.1)	0-7.3	0.05 (0.03)	0-0.10
Picking up object	1.5 (1.5)	0-4.6	0.03 (0.02)	0-0.07
Transfers	1.5 (1.5)	0-4.6	0.02 (0.02)	0-0.05

SE = standard error; CI = confidence interval.
* Estimated proportions and counts might not sum across activities to 100% or 1.0, respectively, because participants can be in more than 1 group if they reported multiple falls.

Environmental barriers and/or limitations in modern prosthetic components could contribute to the prevalence of BoS falls in LLP users. Environmental hazards that disrupt the BoS (eg, cracks in the sidewalk) might be more common than those that disrupt the CoM (eg, collisions in crowds). The lack of active ankle dorsiflexion in most contemporary prosthetic feet could limit the functional shortening of the prosthetic leg required during the swing phase to achieve sufficient toe clearance, increasing the likelihood of a BoS disruption (ie, trip) [13]. Minimum toe clearance of the prosthetic leg during the swing phase is 50% lower in transtibial LLP users with a history of trip-related (ie, BoS) falls than without [33]. LLP users also could be susceptible to BoS falls because of limited or ineffective responses to BoS disruptions. For example, when the prosthetic leg is obstructed during a trip, transfemoral LLP users only select the "lowering" strategy, ignoring the "elevating" strategy, even when the "elevating" strategy is more suitable [20]. In addition, the "lowering" strategy is often unsuccessful in transfemoral prosthesis users because of excessive stance phase flexion (ie, buckling) of the prosthetic knee [20,55]. Therefore, new prosthetic designs with active powered control might be necessary for LLP users to successfully use the full range of available balance response strategies [17]. Clinical balance tests that probe responses to BoS disruptions [27] might be needed to improve fall risk assessment in LLP users [30].

Prevalence of Intrinsic Falls in LLP Users Could Explain the High Rate of Recurrent Falls

Consistent with prior research [1], the results of this secondary analysis confirmed that ambulatory LLP users experience more falls initiated by intrinsic personal factors than imposed by extrinsic environmental factors. A larger proportion of intrinsic falls are typically associated with advanced age (ie, >75 years old) [31,43,45,56]. However, the relatively young mean age of the present sample (50.4 years) suggests that intrinsic falls are unlikely to be attributable to age. Instead, challenges and demands unique to prosthetic ambulation, such as controlling a prosthetic knee (ie, "prosthetic factors") and a decrease in strength [3,28,57], are more likely to be responsible for intrinsic falls. The prevalence of intrinsic falls, which are associated with systemic issues and multiple falls [47], could explain the high rate of recurrent falls (36.3%) that were observed in this analysis. In addition, by placing greater emphasis and quickly identifying and treating intrinsic factors related to fall risk, clinicians could decrease recurrent falls in LLP users. Although modifiable (eg, pain, general health, mobility, strength) [3,53,57] and non-modifiable (eg, level of amputation, cause of amputation, increasing age, altered somato-sensation, and gender) [3,53,57] intrinsic personal factors have been associated with increased fall risk, a history of falls, fall-related injuries in LLP users, other important and modifiable intrinsic factors including prosthetic design, and reaction time [21,58] remain unexamined. How intrinsic factors change across stages of recovery [59] and their synthesis into a clinical test for predicting susceptibility to intrinsic falls could improve fall risk assessment. A full characterization of intrinsic personal factors and their association with falls in LLP users is warranted [60].

LLP Users Reported Different Fall Patterns

Nearly three-fourths of the falls reported by LLP users were categorized as slips (26%), trips (22%), or prosthetic factors (22%). The prevalence of slips and trips corroborates the findings of Rosenblatt et al [33] who reported that, in a small sample of transtibial LLP users, one-fourth of falls were trips and one-fourth were slips. Kulkarni et al [1] reported that 12% of falls in their sample of LLP users were attributed to prosthetic-related factors, approximately half that in the present analysis. These prosthetic-related falls in the prior study included "prosthetic failures" (eg, foot breaking) and "prostheses not working as expected." This suggests that LLP users might be attempting activities that their prostheses do not allow them to do and that new components might increase patient safety. These results also expand the diversity of fall patterns previously identified. Although previously reported in older adults [26,27], incorrect weight shifts and a small BoS, which accounted for 20% of all reported falls, had not previously been described in LLP users. Owing to this variety, neither assessment nor treatment of falls in LLP users can currently be prioritized based on the prevalence of a specific fall pattern.

Walking Was the Most Common Activity at the Time of a Fall

Participants in this study were generally engaged in some form of locomotion, mainly on a level terrain, at the time of a fall. This is consistent with a previous study of a small sample transtibial LLP users in which most falls and stumbles occurred while walking, 83% of which were on level ground [33]. The prevalence of falls while walking is likely attributable to the prominence of walking in our lives and the inherently unstable biomechanics of walking [61]. Falls in LLP users might be more common on a level terrain owing to opportunity (ie, there is more level than uneven terrain), avoiding an uneven terrain, or gait modifications made to preserve "stability" on an uneven terrain. Although challenging [62], when walking on an uneven terrain LLP users adopt a cautious, conservative gait pattern (ie, decreased speed, wider BoS, increased double support time, lowered CoM, and increased upper extremity motion) [22,63-66]. Although potentially imposing additional costs or demands (ie, metabolic), these changes appear to mitigate additional risk associated with walking over an uneven terrain [22,66].

Limitations

LLP users were asked to recall fall events during the past 12 months (ie, self-report). This could have introduced recall bias and led to an underestimation of the prevalence of falls [67,68]. There is currently no consensus regarding recall period when asking LLP users about falls. In addition, commonly adopted definitions of a fall [1,3,5] do not contain prosthetic-specific language (eg, "a fall with or without your prosthesis"). Similar to guidelines proposed for older adults [69], future research could benefit from establishing the time window during which LLP users can accurately recall fall events and their related details and a fall definition that is meaningful to LLP users.

The present analysis is limited by our understanding of the situation in which falls occurred and the role, if any, of prosthetic componentry on fall type. For example, the mental (eg, distraction, urgency) or physical (eg, fatigue) state of LLP users at the time of a fall remains unknown. Additional research characterizing these situations could clarify why falls while walking on a level terrain were prevalent. Future research would benefit from a clearer separation of activity and physical environment and from additional details characterizing the physical environment at the time of a fall (eg, lighting, time of day, indoor or outdoor). Likewise, the role of prosthetic componentry in contributing to or decreasing certain fall types remains to be determined. A comprehensive analysis of the physical, social, economic, and psychological consequences of falls in LLP users is needed to better determine the impact of falls in LLP users. Characterizing fall consequences also could provide a more robust approach to prioritizing clinical and research directions with respect to specific fall patterns.

Conclusion

The primary objective of this secondary analysis was to provide an initial characterization of the circumstances concerning falls in ambulatory unilateral LLP users. The results of this secondary analysis suggest that falls remain frequent in ambulatory LLP users and that clinicians and researchers might wish to prioritize falls from disruptions of the BoS that occur while walking. The secondary objective was to propose and evaluate an LLP user-specific fall-type classification framework and taxonomy. The proposed fall-type classification framework successfully classified all self-reported falls, suggesting that it is comprehensive. Future falls research in LLP users might wish to use a similar taxonomy and framework. With the frequency of falls remaining higher than 50% and the rate of amputation expected to increase [70], falls in LLP users are likely to be a substantial burden on the U.S. health care system. An understanding of the circumstances and consequences associated with falls could lead to previously unidentified targets for assessing and treating fall risk.

Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.pmrj.2018.08.385.

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Appendix 1

Definitions of Fall-related Terms

Fall: An unplanned, unexpected, or unintentional event that occurred during standing, walking, or changing posture and resulted in a body part, other than the feet, coming to rest on the ground or a lower level, other than as a consequence of loss of consciousness, violent blow, stroke, or epileptic seizure [1,34,68].

Intrinsic cause: Precipitating factors initiating a fall that are attributed to the individual (eg, muscle weakness) [29,31].

Extrinsic cause: Precipitating factors initiating a fall that are attributed to the environment (eg, icy driveway, uneven terrain) [29,31].

Note: If intrinsic and extrinsic causes are involved in the precipitating incident leading to a fall, then the primary cause will be interpreted as intrinsic (eg, tripping over an object owing to poor muscle weakness that limited the ability to adequately lift the leg [31]).

Base-of-support fall: Fall initiated by a perturbation (ie, force) applied to the base of support that prevents the base of support from remaining beneath the center of mass [27].

Intrinsic base-of-support falls

Trip or stumble: Fall initiated by obstructing the trajectory of one's foot or leg on an unchanging or unobstructed surface, an assistive device, or one's own body (eg, walking on a level surface but catching the toe because of inadequate foot clearance) [26,27].

Inadequate base-of-support fall: Fall initiated by an error in foot placement that results in a step or stance width that is too small or provides insufficient contact with the support surface (eg, foot is in partial contact with a stair or step or foot placement decreases step width or length).

Extrinsic base-of-support falls

Trip or stumble: Fall initiated by catching the foot or leg on an uneven surface, obstacle, step, or terrain transition (eg, catching the toe in a crack in the sidewalk) [26,27].

Slip: Fall initiated by inadequate friction between the foot and the ground arising from environmental conditions (eg, slipping on an icy sidewalk) [26,27].

Inadequate base-of-support fall: Fall initiated by surface that is too small and/or provides inadequate contact beneath the foot (eg, losing balance on a narrow step stool).

Center-of-mass fall: Fall initiated by a perturbation (ie, force) applied to the center of mass or trunk that acts to displace the center of mass beyond the existing base of support [27].

Intrinsic center-of-mass falls

Incorrect weight shift: Fall from self-induced shifting of body weight beyond the base of support (eg, reaching, turning, transfers) [26].

Extrinsic center-of-mass falls

Push: Fall initiated by the application of a force directed toward the center of mass by another person or object (eg, being pushed by someone while standing still).

Pull: Fall initiated by the application of a force directed away from the center of mass by another person or object (eg, being pulled by someone when rising from a chair).

Collision: Fall initiated by an impact with someone or something while moving (eg, bumping into someone while walking in a crowded street). Note: Bump will be included in this definition

Other types of falls

Intrinsic

Prosthetic factors: Fall initiated by prosthetic behavior that does not align with user intent or expectations and any component of the prosthesis that malfunctions, breaks, fits poorly, or is misaligned (eg, prosthetic knee buckling) [1].

Physiologic factors: Fall in the absence of a physical perturbation, caused by a transient physiologic event (eg, syncope, seizure, or a sudden loss of muscle tone or head movement, vertigo) [26,27,31].

Extrinsic

Loss of external support: Fall initiated by a support structure moving unexpectedly (eg, chair moves unexpectedly from sit to stand) [26,31].