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Current and Emerging Trends in the Management of Fall Risk in People with Lower Limb Amputation

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Abstract

Purpose of Review—People living with lower limb amputation are at an increased risk of falling compared with the healthy geriatric population. Factors of increased age and increased number of comorbidities could compound the already increased risk. The purpose of this article is to highlight recent research associated with fall risk in amputees and provide the reader with evidence to help guide clinical interventions.

Recent Findings—Though research on the topic of falls in people with amputation is becoming more common, there is still a dearth of evidence regarding what contributes to increased fall risk and how to address it in this population. There are recent studies that have examined therapy and prosthetic interventions that could mitigate fall risk in people with amputation, yet there is not enough evidence to develop a consensus on the topic. More research is required to determine what contributes to increased fall rates in people with amputation, and what detriments to an amputee's function or psyche may result after incurring a fall.

Summary—Borrowing from what is known about geriatric fall risk and combining the information with novel and existing approaches to fall mitigation in amputees can offer clinicians the opportunity to develop evidence-based programs to address fall risk in their patients with lower limb amputation.

Keywords

Amputation; Fall risk; Prosthetics; Limb loss

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Introduction

There are over one million people living with lower limb amputation (LLA) in the USA [1] and this number has been increasing, to an ever-younger and wider population, due to the rates of chronic diseases like diabetes and peripheral vascular disease [2]. As a result of gait and balance adaptations from losing a portion of their lower limb, amputees have a higher fall risk than the general geriatric population and other patient groups during all phases of recovery [3, 4]. Unfortunately, falls in people with LLA are a complicated matter, as risk factors and etiology of falls can vary with age and presence of other comorbidities [4]. And falls can occur regardless of clinical characteristics like cause of amputation or anatomical level of amputation [5]. As expected, amputees who are older and have multiple comorbidities or residual limb problems exhibit increased fall rates [3, 4]. However, it has been reported that younger people with LLA who exhibit better balance capabilities also have increased odds of falling [5], raising the question about what “increased fall risk” may actually indicate in this population. For instance, if an injury is not incurred during a fall, does the fall carry a negative consequence to the amputee in any way or is it indicative of poor training, reduced physical capacity, poor prosthetic fit, pain, etc.? Many unanswered questions exist when examining falls in the LLA population. The purpose of this manuscript is to review the recent literature on the topic of falls in people with lower LLA and determine if practicable approaches exist in mitigating fall risk through physical therapy and/or prosthetic interventions.

Definitions/Terminology

At the most basic level, the definition of a fall can vary. Often, common fall definitions for people with LLA lack prosthetic-specific language [6•], neglecting to take into account whether the amputee was or was not wearing their prosthesis at the time of the fall. Circumstances surrounding a fall may contribute to reasons on why someone with LLA lost their balance, and recent research has attempted to establish a framework for categorizing causes of a fall by the location of destabilization of the body [6•]. For instance, catching one’s toe as they walk would be classified as destabilization at the base of support. Additionally, there are a variety of ways that a “faller” is defined in the literature, with authors using categorization of a “faller” or “recurrent faller” or “multiple faller” by the number of fall occurrences in a predetermined amount of time, often the previous 6 to 12 months [5-7]. Lastly, the vast majority of fall research in the LLA population is based on retrospective recollection by the subjects of their fall history, introducing the potential for recall bias into the studies. The authors of this manuscript propose to offer a more comprehensive amputation-focused fall definition of “a loss of balance resulting in the person unintentionally landing on the ground while wearing their prosthesis or not.” This definition implies asking of a secondary question to clarify if the prosthesis was worn during the fall, which provides additional information into potential causes of the fall.

Risk Factors and Sequelae of Falling in People with Lower Limb Amputations

It is logical to conclude that increasing age in people with mobility deficits likely compounds fall risk. According to the most recent statistics, the majority of people with LLA in the USA are over 65 years old and underwent amputation due to dysvascular causes of peripheral vascular disease or diabetes mellitus or a combination of the two [1]. However, within the LLA literature, only one study in the past 10 years has focused specifically on geriatric amputee fall assessment [8]. The Turkish study enrolled a small sample size that was of varying amputation etiology and amputation levels and found that 80% of the subjects experienced a fall in the past year, with 64% reporting multiple falls. Most research on falls in people with LLA has been inclusive of amputees aged 18 and older, with the average age of study subjects being 56 to 64 years old [3, 4]. Furthermore, many study subjects are categorized by the authors as community ambulators [7] according to Medicare Functional Classification Levels (or “K levels”) [9], indicating that subjects are generally functional enough to actively engage with their environment yet are experiencing falls. For example, an author of this manuscript (Clemens) has currently unpublished data in which 46.4% of the subjects ($n = 69$), mean age of 47.1 (14.1) years, reported a fall in the past year with 84% of the study participants being categorized as functional community ambulators (K3 level or higher), though none of the subjects had dysvascular cause of amputation. This being said, people with dysvascular amputation are known to have comorbidities that contribute to increased fall risk. Complications such as peripheral neuropathy [10], balance deficits [11], increased medication use [4], and debility are characteristic risk factors of falling that accompany vascular disease and diabetes. Additionally, there is evidence that amputees who are women and of non-white race are at greater risk for injurious falls [12].

Clinical Outcome Measures to Assess Fall Risk

In physical therapy practice, certain outcome measures are used to determine if a patient is at an increased risk of falling. Specific to the LLA population, several performance-based measures and, to a lesser extent, patient-report outcomes have been used to study fall risk. The frequently administered timed-up-and-go (TUG) test is well established in the literature as an outcome measure to evaluate fall risk in the elderly, with a Centers for Disease Control (CDC) recommended cutoff score of 12 s for the geriatric population [13]. When the TUG is used to examine falls in the LLA population, varying results have been reported. In a seminal study by Dite, people with LLA at risk for multiple falls, inclusive of adults 18 and older, scored greater than 19 s to perform the test [14]. More recently, Sawers and Hafner established cut-off scores for amputees age 18 and older with at least one fall in the past year and those with two or more falls at 8.17 and 9.25 s, respectively [15•]. These much lower cut-off scores may be due to the prosthetic experience of the samples with Dite’s participants being approximately 6 months post-amputation and Sawers’ having a mean time since amputation of 14.3 years.

The Berg Balance Scale (BBS) has been used in several studies to examine balance ability in people with LLA. The BBS is composed of 14 tasks to assess balance ability in standing and has been validated and used extensively in the literature to predict fall risk in multiple populations [16]. Major et al. determined the reliability and validity of the BBS in people with LLA; however, they also reported that the test was unable to distinguish between subjects with greater or lesser fall risk [17, 18]. Wong et al. went on to publish how better performance on certain items from the BBS (indicating better balance ability) actually *increased* the subject's odds of falling [5]. These research results once again suggest that amputees who exhibit higher activity levels and mobility are potentially more likely to fall than more disabled persons with LLA who may limit their activities. These findings suggest that fall risk in people with LLA is not only about physical capacity but may also have a psychosocial context.

As a *result* of being at increased risk for falls, someone with LLA may lack confidence in performing daily tasks and could self-impose limits on participation in community and social activities for fear of injury or embarrassment due to a fall. The Activities-specific Balance Confidence Scale (ABC) is frequently administered in studies examining fall risk in the LLA population [19]. The 16-item measure is reliable and valid for assessing someone's self-perceived confidence in maintaining their balance with a prosthesis while performing a range of tasks [20]. Better ABC scores are associated with improved prosthetic balance ability [14], and the test exhibits a higher cut-off score for fall risk in people with LLA than in the non-amputee geriatric population (80.2% versus 67%, respectively) [15, 21], indicating that despite higher balance confidence, amputees are still at a greater risk of falling than the healthy elderly. Therefore, using common outcome measures like the TUG, BBS, and ABC as well as other tools with recently established fall cut-off scores [15•] to assess potential fall risk in people with LLA could inform clinical practice on developing interventions for fall mitigation.

Current State of Practice

Interventions for reducing the incidence and prevalence of falls typically focus on fall prevention to address this growing health concern. This is particularly true in the older adult population where falls are the number one cause of injury-related death [22]. The Centers for Disease Control (CDC) Injury Center has called for increased attention on fall prevention in the clinical setting due to the frequency of falls and the severity of the consequences [23]. In today's healthcare climate, however, primary care physicians have difficulty incorporating fall prevention into an individual care plan. Many clinicians either do not know how to or do not have time to screen for fall risk [24].

In light of these obstacles, the CDC has developed a toolkit called STEADI (Stopping Elderly Accidents, Death, and Injuries) for clinical use [13]. This resource provides the education and tools necessary to screen for fall risk and refer to the proper allied health practitioner for targeted intervention. The physical therapist involved in treating the older adult population must be familiar with the screening processes and evidence-based interventions. The CDC also provides an extensive list of evidence-based, community programs that reduce the number of falls in the older adult population [25]. Many of these programs offer multifactorial interventions that include strengthening exercises, balance exercises, patient education, and home environment modification [26, 27]. Examples of these evidence-based exercise programs include Tai Chi for Arthritis, Tai Ji Quan for Better Balance, Stepping On, and the Otago Program [28].

Individuals with LLA are at greater risk for falls than age-matched controls; however, few studies have explored the efficacy of exercise programs in fall prevention. Two recent studies examined the implementation of exercise interventions to participants with LLA. Miller et al. found a significant training effect on 16 subjects following a 6-week training program which included lower body strengthening, static and dynamic balance activities, and gait activities [29]. Improvements were demonstrated in gait speed, balance confidence, and dynamic balance. Though the impact on fall incidence was not directly studied, balance and balance confidence do play a role in activity avoidance and prosthetic use which may lead to further fall risk and debilitation [30, 31]. Schafer et al. designed a block randomized control study which found significant improvements in the incidence of falls, gait biomechanics, and gait speed for individuals with LLA between the intervention group and control group following a 12-week individualized exercise program [32]. Both of these studies suggest that administering exercise interventions known to reduce falls in the able-bodied population may also reduce falls in people with LLA.

Borrowing from the geriatric literature on falls is logical due to dearth of evidence in the limb loss population. It has been postulated that fall prevention programs for older adults have a maximal success rate of approximately 30–40% [33]. Minimizing fall risk through prevention programs is critical to improving an individual's overall health and quality of life, while also reducing injuries and associated medical costs. However, we urge that prevention should not be the only intervention when rehabilitating individuals with LLA. Falls may be an inevitable part of regaining mobility at home and in the community during the process of recovery from limb loss. Therefore, additional training in the form of floor to rise training (FRT) and fall arrest training should be provided by qualified healthcare practitioners.

Fall arrest training can be described as learning how to achieve a softer landing during a fall. This type of training has the potential to mitigate injuries during a fall. Common fall-related injuries sustained in the older adult population include traumatic brain injuries, hip fractures, and humeral fractures [34, 35]. Considering the catastrophic nature of these injuries, fall arrest training has as much potential to save future pain, loss of function, and financial burden as fall prevention. There is precedent for training a person how to fall with a softer landing in impact sports, the military, and in martial arts. However, fall arrest training as a physical therapy intervention has not been rigorously studied. In 2014, Arnold et al. examined a program in which fall arrest training aimed at the older adult female population was added to an existing fall prevention program [36]. The fall arrest training included the strengthening of the shoulder girdle, elbow, and postural muscles, along with a range of motion exercises and techniques for achieving a softer landing. This program was designed to address modifiable physical impairments that may alter the mechanics of a forward fall. Results included improvements in upper body strength, upper extremity range of motion, agility, and overall fall risk factors. Another series of studies reviewed the use of martial arts landing techniques to mitigate impact force during a fall. Two of the studies separately demonstrated 27% and 30% reductions in force magnitude through the lateral hip during a sideways fall when using martial arts technique [37, 38]. A third study showed reduced peak force impact through the upper extremity with modifications to elbow flexion angle and body velocity [39]. Additional studies in the same series supported the notion that these skills could be taught safely to individuals with osteoporosis and retained by novice learners [40, 41].

Floor to rise training can be a valuable tool to prevent a long lie after a fall, but is not always included as part of a rehabilitation plan of care [42]. Traditionally, the training consists of teaching an individual a sequence of body postures that will enable a transfer from the floor to a chair or standing position. These postures are taught by beginning with the individual laying on the floor and then progressing to more upright postures until the transfer is completed [43]. More recently, the technique of backwards chaining method (BCM) has been recommended by the American Geriatrics Society to teach FRT [44]. The backwards chaining method breaks down the steps of performing a floor to rise transfer and permits the learner to execute the steps in reverse order. In other words, the individual begins in a standing or sitting position and progresses to the floor. This reverse order sequencing promotes early successes, and therefore confidence, in training. It also reduces the learner's cognitive load by repeatedly practicing and mastering one step before progressing to the next. In this manner, it is possible to teach the physical skills of rising from the floor after a fall while also reducing anxiety in the learner. A recently published systematic review on the BCM found that the technique improves subjects' ability to rise unassisted from the floor, reduces the incidence of falls, and potentially reduces the fear of falling in the older adult population versus other training methods [45•].

None of the studies referenced for fall arrest training or floor to rise training included individuals with LLA as subjects. However, the application of the results of these studies to the LLA population can provide clinicians with additional techniques when developing exercise programs for their patients with limb loss. Further research on these types of interventions should be undertaken in those with LLA to promote awareness, determine the efficacy of the intervention, and assess the effects of such a training program on key outcomes. In the meantime, the literature that does exist for the adult and older adult populations may serve as a guide. In clinical practice, the techniques for floor to rise training are often modified according to an individual's physical impairments and functional limitations. Creativity in applying the technique can be as much a factor as strength or range of motion. Fall arrest training also depends heavily on a technique that can be modified based on patient presentation. The most important clinical consideration in all cases is patient safety. A full accounting of the individual's history, current health status, and potential precautions should be undertaken with the interdisciplinary team prior to the implementation of a fall arrest training program.

Influence of Lower Limb Prosthetic Componentry

The prosthesis should not be overlooked as a variable in rehabilitation when discussing patient interventions and fall prevention. Prosthetic feet and knees are prescribed to individuals based on their level of mobility and are therefore designed to meet specific demands. In particular, microprocessor-controlled feet and knees have an improved ability to contribute to patient safety over their mechanical counterparts. This is due primarily to the ability of the devices to adapt to changing environments in real time, as well as programmability that enables specific features.

Microprocessor-controlled feet (MPF) have the ability to control motion at the ankle. The ankle is articulated which means there is a greater range of motion at the ankle than with a standard carbon fiber foot. Microprocessor feet can therefore adapt to uneven terrain, including hills, and offer additional toe clearance during the swing phase of gait [46, 47]. A lower minimum toe clearance has been linked to trip-related stumbles in the transtibial population which suggests that these types of interventions may be able to prevent future falls [48]. More research is needed to determine how MPF affect fall recovery mechanics and risk.

Microprocessor-controlled knees (MPK) also influence patient safety. MPK provide real-time support for those with transfemoral amputations based on the activity performed, speed of walking, incline of the surface, and type of terrain. In addition to real-time support, MPK have safety features such as stumble recovery, intuitive locking mechanisms, and activity-specific modes. Microprocessor knee improvements in level ground gait parameters such as self-selected walking speed, fast walking speed, step length, and step symmetry have been confirmed by research [49]. Consistency and efficiency in negotiating hills, stairs, and other environmental obstacles have also been confirmed [50]. In addition to improving overall mobility, MPK reduce stumbles and falls, improve balance confidence, and reduce the rate of falls for individuals with amputations above the knee [50-52]. Multiple studies have theorized that this is due to an improved ability for the individual to increase weight-bearing through the prosthesis which results in greater utilization of somatosensory input for dynamic balance [53, 54]. It is also worth noting that these benefits have been realized in community ambulators, for whom MPK are primarily prescribed, and also for those with lower mobility levels such as household ambulators [48, 50].

Emerging Research Evidence of Fall Mitigation Training in Persons with LLA

Multiple studies are currently underway at institutions throughout the country to examine falls in people with LLA. Limitations of previous studies have been recognized and are being addressed by current research in the hopes of better identifying if targeted therapy interventions or particular prosthetic componentry helps to decrease fall risk, specifically in the elderly amputee population. One enticing possibility currently being explored utilizes treadmill training and can be directly translatable to many clinical settings, providing convenient opportunities for rehabilitation professionals to administer fall mitigation training to their patients.

While causes for accidental falls vary, an observational study of older adults in an indoor, free-living environment showed that incorrect weight-shifting, trip or stumble, and a hit or bump combined to trigger more than 70% of the falls [55]. These common causes of falls are all related to postural perturbations and individuals' loss of ability to respond and recover from such perturbations. Recent studies in non-amputee populations have shown that repeated exposures to postural perturbations can be an effective form of practicing to improve fall arrest reactions (i.e., compensatory stepping) and to reduce fall incidence in a free-living environment [56, 57]. The reactive training to unexpected perturbations may be more effective than training that focuses on volitional stepping movements [58]. While this type of training has been studied in many other clinical populations with increased fall risk (i.e., older adults and persons with various types of neurological conditions), its use in the limb loss population is relatively new. Here, we review the current knowledge base regarding the application and efficacy of treadmill-based perturbation training for fall prevention in individuals with limb loss.

Treadmill-Based Perturbation Training for Fall Mitigation

The proliferation of programmable treadmill in the last 10 years enabled a more natural simulation of tripping falls, which typically occur during dynamic situations such as walking. Applications of this technology to the limb loss population began with research to understand the biomechanics of prosthetic gait but are now translating to clinical practice as part of the rehabilitation strategy. The premise of treadmill-based perturbation training is to provide the trainee a safe environment (via use of a safety harness) to experience the unexpected movement of the supporting surface (i.e., belts of the treadmill; Fig. 1). Essentially, a trip occurs when the tripped leg is pulled backward while the trunk continues with forward momentum. The sudden backward acceleration of the treadmill belt simulates the directional uncoupling between the tripped leg and the trunk, prompting a reactive forward step by one leg to arrest the trunk's forward momentum. The treadmill control scheme for accurately replicating tripping falls has been suggested and validated [59, 60]. A typical training protocol involves the participant standing (static) or walking (dynamic) on a treadmill before unexpected perturbations are applied. Participants are typically instructed on how to avoid falling by using the forward recovery step. Treadmills designed specifically for delivering this type of fall prevention training are becoming commercially available [61].

Preliminary Clinical Results

One of the first studies to investigate the clinical efficacy of this type of training in the limb loss population was conducted in 14 high functioning service members (Medicare Functional Classification Level K3 or K4) [62•]. The participants were younger (age = 26 ± 3) with unilateral transtibial amputation due to trauma. They received six sessions of treadmill-based training (30 min each) over a 2-week period. Results of the study showed that after training, the participants exhibited significant improvement in trunk control and fall recovery success rate. The improved trunk control in response to this particular form of perturbation was retained 3 and 6 months after no further training. Participants also reported increased confidence and reduced incidence of falls and near falls in free-living environments. Using a similar training protocol, Crenshaw et al. demonstrated beneficial outcomes in a small group ($n = 5$) of individuals with unilateral, transfemoral, or knee disarticulation limb loss [63].

In addition to showing that treadmill-based perturbation training can lead to improved fall recovery success, it is important to recognize that the training seems to improve participants' trunk control in respond to a trip and stumble. In currently unpublished data, researchers

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observed reduced peak trunk flexion angle and velocity indicating a less drastic and more controlled reaction to the simulated tripping situation. The smaller trunk flexion angle after training suggested a smaller magnitude of body center of mass perturbation, presumably due to the more effective stepping response after training [64].

In summary, recent studies have shown that treadmill-based perturbation training can be an effective rehabilitative protocol for fall prevention in individuals with limb loss. It is exciting to see the programmable treadmill technology previously used only for research being applied to clinical intervention. Utilized as a therapeutic training tool, this is a promising paradigm for advancing rehabilitation care after amputation. However, current evidence regarding the efficacy of this type of training is limited to the higher functioning, relatively younger population with traumatic limb loss. Whether this type of training is feasible and beneficial to a wider LLA population requires further investigation.

Conclusion

Though currently there are no evidence-based protocols proven to reduce falls in amputees, researchers are continuing to investigate the benefits of therapeutic and prosthetic interventions to reduce falls in this high-risk population. Utilizing existing evidence regarding causes and incidence of falls in people with LLA and borrowing from successful interventions in the well-studied geriatric population provide clinicians in post-amputation care with information to formulate programs to assess and treat amputee patients who are inherently at risk for falling. Prosthetic and rehabilitation professionals can benefit their patients with LLA by educating them on their increased risk of falling and provide guidance on mitigating their chances of injury during a fall.

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Fig. 1.

Treadmill-based perturbation training of a subject with right transtibial amputation