Evidence Note | The Biomechanics of Ambulation after Partial Foot Amputation

Key Points

- Partial foot amputation is the most common type of amputation in the United States and occurs nearly twice as frequently as either transtibial (below-knee) or transfemoral (above-knee) amputation.
- There is strong evidence that partial foot amputation affects multiple aspects of gait including causing a loss of power generation at the affected ankle.
- There is limited evidence to support our understanding of the influence of prosthetic and orthotic intervention. The available evidence suggests that "above ankle" devices may be better able to restore the center of pressure excursion than "below ankle" approaches.
- Methodologically strong research is required to support existing investigations and improve the depth of knowledge regarding the biomechanics of ambulation after partial foot amputation.

Scope of Review

The purpose of this Evidence Note is to facilitate access to knowledge regarding the biomechanics of ambulation after partial foot amputation (PFA) and the effect of prosthetic and orthotic interventions.

Published research that evaluated some aspect of gait in persons with PFA, with or without a prosthesis or orthosis, was considered as part of this Evidence Note. Consistent with the International Standards Organization (ISO) definition of PFA,[1] publications describing the gait of persons with Syme's amputation (ankle disarticulation) were not considered.

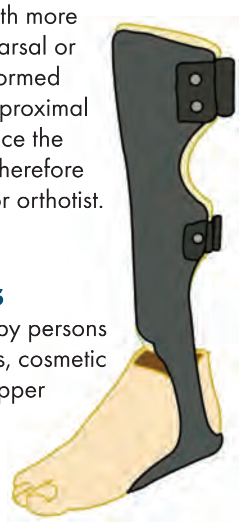
Etiology

PFA is an all-too-common sequel to advanced vascular disease, typically secondary to diabetes.[2-6] Less commonly, PFA may result from trauma, limb deficiency, frostbite, or systemic disorders.[7-9]

Based on data from the Vital and Health Statistics, Ambulatory and Inpatient Procedures[10] and accounting for the increase in the population since 1996, it can be estimated that there are approximately 1.27 million Americans living with lower-limb amputation. More than 618,000 persons have a PFA, making the procedure nearly twice as common as either transtibial (below-knee) or transfemoral (above-knee) amputation.[10] Estimates of the prevalence of limb loss in the United States for 2005 are comparable.[11]

Given that the incidence of PFA increases exponentially after 40 years of age, almost in parallel with the incidence of diabetes,[12] one could contend that the number of persons with PFA will increase as the number of older persons and those living with diabetes increases.[13] Similar observations have been made about the increasing incidence of lower-limb amputation more broadly.[11]

The vast majority of PFA involve the toes and/or metatarsophalangeal joint (76 percent) with more proximal procedures, including transmetatarsal or mid-tarsal amputation, less frequently performed (24 percent).[10, 14] Persons with amputation proximal to the metatarsophalangeal level experience the most significant functional deficit and are therefore likely to seek treatment from a prosthetist or orthotist.



Descriptions of Prosthetic and Orthotic Interventions

A wide range of devices have been used by persons with PFA, including foot orthoses, toe fillers, cosmetic silicone prostheses, ankle-foot orthoses, slipper sockets, or clamshell-type prostheses.[15-20] These devices are typically used with regular footwear, but on occasion may be used with "extra depth" or custom shoes. Shoe modifications, such as rocker soles, have also been used as an adjunct to prosthetic and orthotic intervention.

Generally, the extensiveness of the intervention is proportional to the extent of tissue lost. Persons with amputation affecting the toes or metatarsals may use relatively simple insoles or toe fillers. These devices are usually made from various foams or silicone-type materials aimed at redistributing pressure (typically away from the end of the remaining foot) and thereby preventing skin breakdown and ulceration. By comparison, persons with amputation at the Chopart level (midtarsal disarticulation) may use a more extensive clamshell-type prosthesis incorporating a rigid laminated socket that encompasses the leg and remaining foot. As well as protecting the residuum from skin breakdown, these devices aim to improve gait by replacing the effective foot length.

Summary of the Evidence

A single systematic review describing the biomechanics of ambulation after PFA was identified.[21] This review formed the basis of the American Academy of Orthotists and Prosthetists (the Academy) Eighth State of the Science conference. The review appraised 28 publications from an unconstrained literature search to December 2006. The review included findings from a doctoral dissertation[22] that has since been published.[23, 24] The additional studies[25, 26] published since this review did not meet the criteria defined in the scope of this Evidence Note.

The majority of publications included in this systematic review were observational[i] with only a few experimental studies[ii] comparing the effect of different prosthetic and orthotic interventions on gait.[21]

While the review concluded that there was a "high" level of evidence that PFA affects many aspects of gait (i.e., temporospatial, ankle kinematics and kinetics, as well as plantar pressures), there was little confidence in the evidence regarding how these aspects of gait are changed by PFA or prosthetic and orthotic intervention.[21] For example, there was a "high" level of evidence that PFA had an effect on sagittal plane ankle kinematics during gait but only a "low" level of evidence that PFA changes the magnitude or timing of the dorsiflexion peak during stance or that differences exist based on amputation level.

In general, there is "insufficient" evidence regarding the efficacy of particular prosthetic and orthotic interventions because the majority of publications were observational and the few experimental studies were often inadequately designed.[21]

The depth of our understanding of the effects of PFA and the influence of prosthetic and orthotic intervention on the biomechanics of walking has been limited by a number of consistent flaws in the design of the research.[21] For example, amputee cohorts tended to be quite heterogeneous in terms of time since amputation,[6, 28-32] amputation level (including the number of toes amputated),[9, 33-35] age,[9, 28] and involvement of the contralateral lower limb.[28-31] Experimental studies often failed to match study groups to control for the influence of systemic disease.[6, 32, 34, 36] This makes it difficult to know whether the differences observed between experimental conditions reflect the intervention or merely the underlying disease in one of the experimental groups.

[i] A type of study that observes individuals and measures particular outcomes. No attempt is made by the researchers to affect the outcome.

[ii] A type of investigation in which the researchers systematically manipulate the experimental conditions and in doing so, determine whether this affects the outcome.[27]

Despite these problems, there is some limited evidence describing how persons with PFA walk and the influence of prosthetic and orthotic intervention. The following provides a brief summary of the findings of the systematic review; however, more research is needed to improve the level of confidence in these findings.[21]

Persons with PFA walk at much the same speed as appropriately matched controls.[33, 37] The slower velocity often observed in persons with PFA[28-33] seems to be attributable to the influence of diabetes, rather than the amputation itself.

Power generation across the affected ankle during gait is virtually negligible once the metatarsal heads have been compromised, regardless of the residual foot length or the type of prosthetic and orthotic intervention provided.[6, 7, 23, 38]

Insoles, toe fillers, and slipper sockets do not allow the center of pressure (CoP) to progress beyond the end of the remaining foot until after contralateral heel contact, when weight is shifted to the unaffected limb.[23, 39] In contrast, clamshell-type devices often provided to persons with Chopart amputation seem to normalize the CoP excursion[23, 39] as did a BlueRocker™ ToeOff® orthosis.[40]

It has been hypothesized that the ability of a prosthesis to restore the effective foot length requires a suitably stiff forefoot capable of supporting the amputee's body mass, a socket or anterior leg shell capable of comfortably distributing to the leg and remaining foot the interface pressures caused by loading the toe lever, and a relatively stiff connection between the foot and leg segment to help moderate the moments caused by loading the toe lever.[21, 23, 39] Either a rigid ankle, a free joint with a dorsiflexion stop, or the sort of stiffness inherent in a BlueRocker ToeOff orthosis may be appropriate.[21, 39, 40]

There is a moderate level of evidence that PFA causes an increase in peak forefoot pressures compared to the contralateral side.[30, 36, 41-44] There is insufficient evidence to suggest that prosthetic and orthotic interventions have an effect on pressure distribution compared to footwear alone because only one paper[30] directly compared various pressure-reduction interventions.

Future Research

There is a need to improve the depth of knowledge on this topic. Well-designed observational studies are needed to help answer basic questions about the gait of persons with PFA so that we can move toward well-rationalized comparative-effectiveness studies of prosthetic and orthotic interventions.[21]

In some cases, the ''low" level of evidence on this topic could be improved by independent verification of findings that are currently based on a single, small, well-executed investigation whose evidence cannot, in isolation, be vested with great confidence.[21] In other cases, consistent flaws in research design limited confidence in the findings, and researchers should consider these issues when designing future investigations.[21]

Although challenging, many of the flaws in research design can be addressed with careful consideration and planning. For example, researchers should better match amputee and control groups for systemic disease, age, and contralateral involvement; randomize the order of experimental conditions; employ repeated-measures designs; and better describe the prosthetic and orthotic interventions being studied.[21]

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