

International Encyclopedia of Rehabilitation

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Partial Foot Amputation: Aetiology, Incidence, Complications, Prosthetic Intervention and a Characterisation of Gait

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Summary

Partial foot amputation (PFA) is a common sequel to advanced vascular disease secondary to diabetes and its complications but may also occur due to injury, infection, or birth defect. PFA affects about 2 per 1000 head of population in industrialised countries making it the most common type of amputation surgery. PFA is associated with a significant failure rate and numerous complications including skin breakdown, ulceration and equinus contracture which can lead to subsequent and more proximal amputation.

A variety of interventions have been used to manage the partially amputated foot including insoles or toe fillers through to extensive prostheses that encompass the leg and remnant foot. These devices may serve several functions such as relieving pressure from sensitive areas or restoring the effective foot length.

Formally evaluating how persons with PFA walk and the influence of prosthetic intervention is a relatively recent phenomenon. Investigations have identified a number of abnormal movement patterns once the ball of the foot has been affected. These movement patterns are consistent with the inability to [generate power](#) at the ankle joint using the calf musculature and restore the lost length of the foot so it can be used effectively for weight bearing. A number of compensatory adaptations have been observed that may be useful to spare the end of the residuum from high pressures, such as keeping the [centre of pressure](#) well behind the end of the stump until the opposite limb is on the ground when body weight can be shared between both limbs.

Research has confirmed that prostheses in combination with footwear can relieve pressure from the end of the residuum and that specific designs can restore the effective foot length. Further investigation is needed to better understand the influence of prosthetic intervention and paint a more comprehensive picture of the effects of prosthetic intervention.

Introduction

The International Encyclopaedia of Rehabilitation aims to provide a synthesis of the ‘state-of-the-science’ in principal areas of rehabilitation in an easily accessible internet resource for people with disabilities, the general public, students, health professionals and researchers.

This article on partial foot prosthetics will provide an overview of the topic for those wanting summary information, or as a stepping stone to more detailed material. To aid navigation of the article, the content has been sectioned to provide background information including: definitions, aetiology, incidence and a description of common complications. Subsequent sections describe common prosthetic interventions and characterise the gait of people with

partial foot amputation (PFA). The later section on gait uses a range of nomenclature common to the analysis of human walking. To assist those not intimately familiar with gait nomenclature, definitions have been ‘hyper-linked’ to key terms.

Background

Definition and types of partial foot amputation

PFA could be described as amputation affecting a portion of the fore, mid or hind foot, but does not include amputation disarticulating the ankle joint (Symes), consistent with the International Standards Organisation definitions (International Organisation for Standardisation 1989).

There are numerous levels of PFA that can be described in a variety of ways. Some amputations are termed ‘longitudinal’ given that they affect the structure of the foot along its length – resection of several metatarsals or ‘rays’ would be a typical example. Other procedures are described as ‘transverse’ meaning that they transect a portion of the foot - a transmetatarsal (TMT) amputation (Figure 1a), as its name suggests, transects the metatarsals through their shaft.

About three-quarters of all PFA involve the toe(s) and/or disarticulate the metatarsophalangeal joint (Figure 1a). More proximal amputations, including transmetatarsal (Figure 1b) or mid-tarsal amputation are performed less frequently (Australian Institute of Health and Welfare 2009c; Dillingham et al. 2002a; Owings and Kozak 1998). [Tarsometatarsal](#) and [transtarsal](#) amputations are commonly described using eponyms such as Lisfranc (Figure 1c) or Chopart (Figure 1d) after the surgeons who coined these procedures, as are Boyd and Pirogoff procedures for the hind-foot.

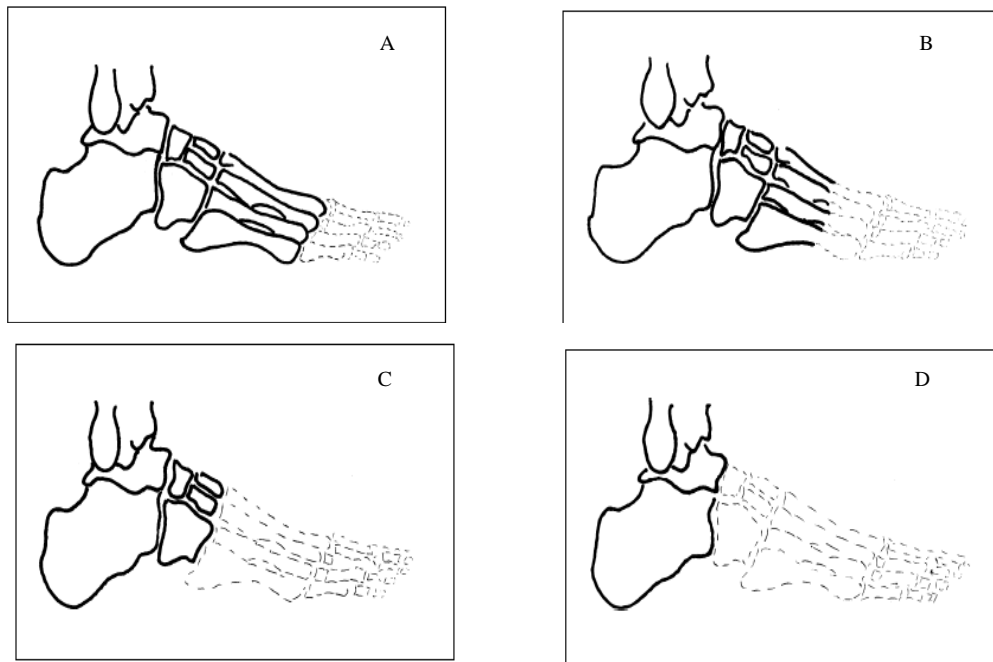


Figure 1. Schematic of various levels of partial foot amputation: (A) disarticulation of the metatarsophalangeal joint, (B) transmetatarsal, (C) tarsometatarsal (Lisfranc) and (D) transtarsal (Chopart) (D).

Aetiology and prevalence

PFA is an all too common sequel to advanced vascular insufficiency, usually secondary to diabetes and its complications (Bowker 1997; Bowker 2007; McKittrick et al. 1993; Miller et al. 1991; Mueller et al. 1995; Mueller et al. 1998; Sanders and Dunlap 1992). The published literature also includes examples of PFA as a result of trauma, limb deficiency, frostbite or systemic disorders such as Toxic Shock Syndrome (Dillon 2001; Greene and Cary 1982; Pinzur et al. 1997; Tang et al. 2004).

Unfortunately, it is impossible to determine the prevalence of partial foot amputation given that these data tend to be reported on a national level and therefore, subject to the limitations imposed by the way different organisations collect and report such data. Minor amputations, such as those affecting the toes (Adams et al. 1999), may not be recorded. The counting of amputation procedures (Australian Institute of Health and Welfare 2009c) or discharges (Dillingham et al. 2002a) is common, but artificially inflates the number of people living with amputation by about 25% given the incidence of repeat amputation (Dillingham et al. 2005; Sambamoorthi et al. 2006).

Despite such limitations, it is possible to estimate the number of persons with PFA. Based on data from the Vital and Health Statistics, Ambulatory and Inpatient Procedures (Owings and Kozak 1998) and accounting for the increase in the population of the United States of America since 1996 when these data were recorded, it can be estimated that there are approximately 1.27 million Americans living with lower extremity amputation. More than 618,000 persons have a PFA making the incidence about 2 per 1000 head of population which is similar to other industrialised nations¹. PFA is nearly twice as common as either

¹ Data from the Australian Bureau of Statistics (Australian Bureau of Statistics 2007) shows that the rate of amputation in persons aged 45 and over is 7 per 1000 head of population which, given that PFA accounts for about half of all lower extremity amputations (Australian Institute of Health and Welfare 2009c) makes the

transtibial (below-knee) or transfemoral (above-knee) amputation (Australian Institute of Health and Welfare 2009c; Owings and Kozak 1998; Reiber 2000). Given that the incidence of amputation are 2-3 times higher when considering groups based on race or ethnicity (Dillingham et al. 2002b; Gujral et al. 1993; Lavery et al. 1996) the proportion of persons with PFA in minority groups may be much higher. These differences may reflect the lack of available primary health care and preventative services (Feinglass et al. 2005; Rucker-Whitaker et al. 2003), particularly for those living in poverty (Wachtel 2005).

It has been projected that the number of persons with amputation (and presumably PFA) will increase as the number of older persons and those living with diabetes increases (Wild et al. 2004; Ziegler-Graham et al. 2008). The number of people living with limb loss in the US is expected to double by 2050 (Ziegler-Graham et al. 2008). Unfortunately, these estimates are based on data from the mid 1990s and may not fairly account for the effects of public health initiatives to reduce the prevalence of limb loss. Reducing the underlying risk of limb loss through education and targeted foot-screening programs has been effective in reducing the risk of foot ulcers and subsequent amputation (Mayfield et al. 2000; Rith-Najarian and Reiber 2000; Streine et al. 2005). More recent data from Australia (Australian Institute of Health and Welfare 2009b) shows that the number of lower extremity amputations performed, including PFA, has remained relatively constant between 2000-2007 despite a 9.7% increase in Australia's population (1.86 million persons) (Australian Bureau of Statistics 2009) and a substantial increase in the increase of type II (63%) and type I diabetes (30%) (Australian Institute of Health and Welfare 2009a) across this period. These data challenge the notion that the number of amputees will increase as the population grows and the incidence of diabetes increases. More work in this area is necessary to accurately discern the current trends.

Complications

There is considerable evidence highlighting that PFA is associated with a significant failure rate (Hodge et al. 1989; Lynch and Kanat 1991; Miller et al. 1991; Millstein et al. 1988; Mueller and Sinacore 1994; Sage et al. 1989; Sanders and Dunlap 1992) and numerous complications including ulceration or skin breakdown (Brand 1983; Mueller and Sinacore 1994; Sage et al. 1989), equinus contracture (Chrzan et al. 1993; Garbalosa et al. 1996; Mueller and Sinacore 1994; Parziale and Hahn 1988; Sanders 1997), secondary amputation to a more proximal level or of the contralateral limb (Dillingham et al. 2005; Ebskov and Josephsen 1980) and even death (Dillingham et al. 2005; Izumi et al. 2006).

The majority of persons who undergo a PFA can expect complications (Pollard et al. 2006); particularly when concomitant health problems such as diabetes, vascular disease, hypertension or end-stage renal disease are present (Pollard et al. 2006). Complications secondary to PFA are wide ranging.

Only about half of all PFA heal uneventfully with the rates varying from 44-57% in diabetic populations (Pollard et al. 2006; Stone et al. 2005). These rates of healing are about 10% better in non-diabetic groups (Pollard et al. 2006). Between 30-50% of persons who undergo PFA will experience skin breakdown (Mueller et al. 1995; Pollard et al. 2006; Sage et al. 1989), ulceration (Santi et al. 1993), skin grafts (Mueller and Sinacore 1994; Wood et al. 1987) or wound failure (ie., dehiscence) (Pollard et al. 2006).

incidence of PFA similar to that of the USA when you consider that most amputations occur in persons over 40 years of age (Australian Institute of Health and Welfare 2009c).

These complications are often experienced in the first few months after PFA. There are several factors that are thought to contribute to the high incidence of skin breakdown including peripheral neuropathy, equinus contracture and limited joint mobility.

Peripheral neuropathy is a common complication of diabetes mellitus and the vast majority (89%) of persons undergoing PFA show evidence of peripheral neuropathy (Sanders and Dunlap 1992). This neuropathy is a significant factor (Cavanagh et al. 1992) because it allows minor trauma to go unnoticed which may progress to skin breakdown and subsequent infection (Pecoraro et al. 1990). Monofilament tests have been shown to be a strong indicator of an insensate foot (Mueller et al. 1989) and should be considered a routine part of a clinical examination.

Equinus contracture (Barry et al. 1993; Parziale and Hahn 1988) and limited joint range of motion have been associated with changes in the mechanics of walking and may cause localised pressure on the residuum which, in turn, can contribute to skin breakdown (Fernando et al. 1991; Mueller et al. 1989; Sage 2007).

PFA is also associated with a high rate of subsequent amputation and mortality. While acknowledging the variation that exists between investigations, about 14-45% of persons who underwent a PFA experienced subsequent amputation surgery (Dillingham et al. 2005; Ebskov and Josephsen 1980; Hodge et al. 1989; McKittrick et al. 1993; Miller et al. 1991; Mueller et al. 1995; Mueller and Sinacore 1994; Pollard et al. 2006; Sage et al. 1989; Sanders and Dunlap 1992; Santi et al. 1993; Thomson et al. 2001). About two-thirds of cases involved surgery on the same limb and the remaining one-third on the contralateral lower limb (Dillingham et al. 2005). Most secondary surgeries occur within the year (Ebskov and Josephsen 1980; Mueller et al. 1995; Mueller and Sinacore 1994) with rates dropping sharply after the first month (Mueller et al. 1995). Unfortunately, about one-third of those who underwent an initial PFA required two or more amputation surgeries within 12 months (Dillingham et al. 2005). Of those who progressed to a higher amputation level, approximately two-thirds were at the transtibial level and one-third at the transfemoral level (Dillingham et al. 2005; Mueller et al. 1995; Pollard et al. 2006). A large proportion of those who underwent subsequent amputation surgery had some form of vascular reconstructive surgery within the three-months prior to PFA (Mueller et al. 1995).

Of those who underwent PFA, about 15-30% died within 12 months (Dillingham et al. 2005; Mueller et al. 1995; Schofield et al. 2006; Stone et al. 2005). Longer-term studies show mortality of 16% (Mueller et al. 1995), 39% (Lee et al. 1993) and 48% (Santi et al. 1993) at 4.5, 8 and 10 year intervals, respectively. The mortality rate of toe and PFA is lower than that associated with transtibial or transfemoral amputation (Izumi et al. 2006; Lee et al. 1993).

Overview of available prostheses

Introduction

A variety of different interventions have been used to manage the partially amputated foot. As a generalisation, the extensiveness of the intervention tends to be proportional to the extent of tissue lost. While often not readily apparent, most devices tend to serve multiple functions. A device might, for example, aim to minimise the likelihood of ulceration and skin breakdown, restore the effective foot length and reduce pressure from the sensitive distal end of the residuum by redistributing body weight to other parts of the foot or even the leg.

The following section introduces some of the common types of prostheses used by persons with partial foot amputation and is designed to provide basic information about the design and expected function of common interventions. More comprehensive information can be found in a variety of texts, such as that by Condie and Bowers (2004).

Below-ankle interventions

Persons with amputation of some or all of the toes, or even disarticulation through the metatarsophalangeal joint, tend to use 'below-ankle' interventions. The trimlines of these devices remain below the malleoli and as such, they can be quite cosmetic. Common below-ankle interventions include: insoles, toe filler, slipper sockets including silicone cosmetic devices (Figure 2-3).

Toe fillers and insoles (Figure 2) tend to be made from various closed-cell foams and are often provided to fill the shoe and/or redistribute pressure away from parts of the foot that might be sensitive or likely to break down, such as the sole under the metatarsal heads. Different densities of foam are common in the one device with some areas including very soft materials for pressure relief (e.g., under the metatarsal heads) while other parts of the same device are quite stiff (e.g., under the shaft of the metatarsals and heel) with a view to realigning the skeletal structures and help support more of the axial load.



Figure 2. Example of an insole with toe-filler.

Some types of below-ankle interventions incorporate a socket that encapsulates the whole of the remnant foot. In the case of a silicone cosmetic prosthesis, the device (including the forefoot) is made entirely of silicone (Figure 3). Pigments are added to colour match the silicone and finer details are often done in-person with the prosthetist matching details to the other foot. These devices are donned by lubricating the residuum and easing the device on. Thermoplastic or laminated sockets are also commonly used and in these cases, a foam forefoot is often bonded to the socket and shaped to fill the shoe. On occasion, a carbon fibre foot plate may be bonded onto the inferior surface of the socket (and covered with foam to fill the shoe) with a view to restoring the effective foot length. These types of devices are most commonly, but not exclusively, used by persons with amputation at the transmetatarsal or tarsometatarsal levels.



Figure 3. A cosmetic silicone prosthesis (left) and a prosthesis incorporating a plastic socket (right)

Above-ankle interventions

Persons with tarsometatarsal or transtarsal amputation often use more substantive interventions, such as a clamshell prosthesis or ankle foot orthoses (AFOs) such as those illustrated in Figures 4 and 5.

An AFO is often made of either thermoplastic or carbon fibre and is typically incorporates an insole or toe filler as an integral part of the device. Other devices, such as the carbon fibre AFO illustrated in Figure 4, can be used in conjunction with a silicone cosmetic prosthesis.

The AFO extends above the ankle and as such, has potential to influence motion of the joint depending on its design. The AFO can be designed to restriction motion given the inherent stiffness of the material. Parts of the material can be trimmed away from around the ankle to reduce its stiffness thereby permit varying degrees of movement and support. Some AFOs have ankle joints and can be designed to allow unrestricted ankle movement or eliminate motion in one direction (e.g., free [plantarflexion](#) but no [dorsiflexion](#)).



Figure 4. A carbon fibre Ankle Foot Orthosis (AFO) used in conjunction with a silicone prosthesis. The stiffness of the strut provides resistance to the leg as it progresses forward over the stance foot.

The socket of a clamshell prosthesis encompasses both the residuum as well as the leg eliminating motion at the ankle. (Figure 5). The socket is often made of fibre reinforced resin with a removable window in the side of the socket to allow the bulbous end of the stump through the narrow part of the socket just superior to the ankle joint (Figure 5). The prosthetic forefoot is often made of relatively stiff foam or even a carbon fibre plate. Some

devices have been made by bonding the distal portion of a prosthetic foot, such as used by persons with transtibial amputation, onto the front of the socket.

Given that the socket encompasses most of the leg, a large proportion of the client's body weight can be redistributed away from the residuum. The extensive socket and locked ankle allow the [moments](#) and forces caused by walking on the device to be comfortably spread over the large surface area of the leg and help compensate for the atrophy and weakness of the calf musculature observed in persons with tarsomatatarsal and transtarsal amputation.



Figure 5. A Clamshell partial foot prosthesis. The removable window allows the bulbous end of the residuum to pass through the narrow section just above the ankle joint. Once donned, the window is closed and strapped in place.

Characterisation of PFA gait and the influence of prosthetic intervention

Introduction

This characterisation explores a range of different adaptations including: reductions in walking velocity in those with diabetes, reductions in the rate of work or [power generation](#) at the affected ankle and compensatory increases in muscle work at the hip joints. Reductions in ankle [plantarflexion](#) during late [stance](#) and the limited excursion of the [centre of pressure](#) are illustrative examples of other adaptations typically observed in persons with PFA.

Overview of the evidence base

Although partial foot prostheses have been commonly used for many decades, formally evaluating their efficacy using research methods has only recently become a subject of interest. A synthesis of the available evidence was recently published by the American Academy of Orthotists and Prosthetists as part of the 8th State-of-Science conference into the biomechanics of ambulation after PFA (Dillon et al. 2007b). The review (Dillon et al. 2007a) appraised 28 publications from an unconstrained literature review to December 2006, including a dissertation (Dillon 2001) that has since been published (Dillon et al. 2008a; Dillon and Barker 2008). A couple of publications (Burger et al. 2009; Kanade et al. 2008) have emerged since this review and extend the body of literature. These have been synthesised into the following sections to extend and update the systematic review.

Because most of what is known about the gait of persons with PFA and the influence of prosthetic intervention has arisen from [observational studies](#), not [experiments](#), there is limited evidence regarding the efficacy of one intervention over another (Dillon et al. 2007a). This is

typical for emerging areas of research because studies of effectiveness are difficult to execute well without observational studies that first seek to document anomalies and propose hypotheses that can subsequently be tested experimentally (Dillon et al. 2007a).

Given this understanding, the depth of our understanding of partial foot amputee gait and the influence of prosthetic intervention is understandably limited. While there are ‘high’ levels of evidence that PFA influences multiple aspects of gait including: [temperospatial](#) parameters, ankle [kinematics/kinetics](#) and [plantar pressures](#) there is less confidence in the evidence regarding more detailed statements about exactly how these aspects of gait are affected (Dillon et al. 2007a). As an illustrative example, there is a ‘high’ level of evidence that PFA has 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](#) (Dillon et al. 2007a). The limited confidence in measures of ankle dorsiflexion arises from discrepancies between studies of barefoot walking (Boyd et al. 1999; Burger et al. 2009; Garbalosa et al. 1996; Tang et al. 2004) and investigations including footwear and a prosthesis (Burger et al. 2009; Dillon 2001; Tang et al. 2004). When footwear and a prosthesis were included in the experimental condition, ankle dorsiflexion was exaggerated (Burger et al. 2009; Dillon 2001; Tang et al. 2004). Subsequent work demonstrated that the [marker sets](#) being used in the footwear/prosthesis conditions were not robust to deformation of the prosthetic forefoot or slipping of the residuum within the prosthesis (Dillon et al. 2008b) which is why these measures were somewhat erroneous.

There are a number of consistent methodological flaws endemic in the current body of literature; most due to the difficulties recruiting research subjects. For example, amputee cohorts tended to be quite variable in terms of time since amputation (Kelly et al. 2000; Mueller et al. 1998; Mueller et al. 1997a; Mueller and Strube 1997; Mueller et al. 1997b; Salsich and Mueller 1997), amputation level (including the number of toes amputated) (Boyd et al. 1999; Burnfield et al. 1998; Greene and Cary 1982; Kanade et al. 2006), age (Greene and Cary 1982; Mueller et al. 1997a) and involvement of the [contralateral](#) lower limb (Mueller et al. 1997a; Mueller and Strube 1997; Mueller et al. 1997b; Salsich and Mueller 1997). [Experimental studies](#) often failed to match study groups to control for the influence of systemic disease such as diabetes (Boyd et al. 1999; Kelly et al. 2000; Mueller et al. 1998; Randolph et al. 2002). These shortcomings make 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.

Despite the limitations of our current evidence, there are a number of observations that are consistently reported across multiple investigations. These can be used to characterise the gait of persons with PFA and the influence of prosthetic intervention while acknowledging that more research is needed to improve the level of confidence in these observations.

Characteristics of PFA gait and the influence of prosthetic intervention

The following section aims to characterise the gait of persons with PFA and does so by describing several unique aspects of gait thought to be typical of this population including: reductions in [walking velocity](#) in persons with diabetes and vascular disease; changes to the normal excursion of the [centre of pressure \(CoP\)](#); reductions in [power generation](#) across the affected ankle and compensatory adaptations at the hip joints bilaterally; reductions in ankle [plantarflexion](#) during terminal stance and increases in peak forefoot pressures. Where necessary, adaptations thought to be characteristic of a particular level of amputation, intervention or underlying disease have been clearly stated.

Walking velocity

Persons with PFA secondary to diabetes and peripheral vascular disease walk at about two-thirds the speed of healthy persons without amputation (Kanade et al. 2006; Kelly et al. 2000; Mueller et al. 1997a; Mueller and Strube 1997; Salsich and Mueller 1997). The slower [walking velocity](#) so often characteristic of PFA gait is likely to be attributable to the influence of diabetes and other systemic disease rather than the amputation *per se*. When appropriately matched to control for the influence of systemic disease, it appears that persons with PFA (and no systemic illness) walk at the same speed as their peers without amputation (Kanade et al. 2006; Pinzur et al. 1992).

Changes to the centre of pressure

Once the metatarsal heads are surgically compromised - through [transmetatarsal](#) or [tarsometatarsal](#) amputations - the [CoP](#) remains well behind the end of the residuum until the opposite foot contacts the ground and body weight can be transferred to the unaffected limb (Dillon and Barker 2008; Dillon and Barker 2006a). This adaptation would be an effective strategy to spare the end of the residuum from the extremes of force observed during late [stance](#) (Dillon and Barker 2008). The below-ankle interventions commonly provided to these groups have not been shown to restore the normal progression of the CoP along the length of the foot.

It has been hypothesised that the ability of the prosthesis to restore the effective foot length relies on three elements: a suitably stiff forefoot capable of supporting the amputees body mass; a socket capable of comfortably distributing pressures caused by loading the prosthetic forefoot to the leg and residuum; and a relatively stiff connection between the foot and leg segments to help control the [moments](#) caused by loading the prosthetic forefoot (Dillon and Barker 2008; Dillon and Barker 2006a; Dillon et al. 2007a). Only some of the above-ankle interventions (eg. clamshell prostheses, Blue Rocker Toe-Off AFO) fulfil these criteria and have shown that the CoP was able to progress beyond the end of the residuum commensurate with the peak [ground reaction forces](#) (Dillon and Barker 2008; Dillon and Barker 2006a; Wilson 2005).

Reductions in ankle power generation and compensatory adaptations

Once the metatarsal heads are compromised, [power generation](#) across the affected ankle is virtually negligible (Burger et al. 2009; Dillon and Barker 2008; Mueller et al. 1998; Tang et al. 2004) irrespective of residual foot length or the type of intervention (Dillon et al. 2007a). Interestingly, while the below-ankle devices provided to these amputees (Burger et al. 2009; Dillon and Barker 2008; Mueller et al. 1998; Tang et al. 2004) allowed ankle motion, power generation was comparable to that observed in persons with [transtarsal](#) amputation wearing clamshell prostheses (Figure 5) where ankle motion was eliminated (Dillon and Barker 2008). It is unclear why persons with amputation proximal to the metatarsophalangeal joint do not use the available [plantarflexor musculature](#) to generate power but it may be a useful means of avoiding localised pressure or shear force on the end of the residuum (Dillon and Barker 2008).

Reductions in ankle power generation on the prosthetic limb during late [stance](#) are commensurate with increased power generation across the [contralateral](#) hip (Dillon and Barker 2008). Similarly, increased hip power generation was also observed on the affected limb during early stance (Dillon and Barker 2008). This suggests that the hip joints have

become the primary source of power generation to compensate for the limited power generated across the affected ankle (Dillon and Barker 2006b).

Reductions in ankle plantarflexion

Reductions in ankle [plantarflexion](#) have been observed in a number of investigations when amputation is proximal to the metatarsophalangeal joint (Burger et al. 2009; Dillon and Barker 2008; Mueller et al. 1998; Tang et al. 2004). In persons using below-ankle devices, the normal pattern of plantarflexion motion was observed but the peak angle was greatly reduced. Confidence over the peak plantarflexion angle remains limited given uncertainty about differences in [walking velocity](#) between experimental groups (Burger et al. 2009; Mueller et al. 1998; Tang et al. 2004) and the robustness of the [marker sets](#) used (Burger et al. 2009; Dillon and Barker 2008; Mueller et al. 1998; Tang et al. 2004) to capture this motion (Dillon et al. 2008b).

In the above-ankle clamshell designs (Figure 5), the ankle is immobilized inside the prosthetic socket. The small motion measured in studies of gait is assumed to be from the prosthetic foot deflecting under load (Dillon 2001).

Plantar pressure

A number of investigations have observed increased peak forefoot pressures compared to the [contralateral](#) limb in persons with PFA (Armstrong and Lavery 1998; Garbalosa et al. 1996; Lavery et al. 1995; Mann et al. 1988; Mueller et al. 1997b; Randolph et al. 2002). While this observation is consistently reported, there is insufficient evidence to suggest that prosthetic intervention has an effect compared to footwear alone because only one investigation drew this comparison (Mueller et al. 1997b). In this investigation a number of interventions were tested, many at the same time, which made it impossible to determine which were effective. It is likely that gait adaptations, such as reducing walking speed, were also employed to moderate the magnitude of peak pressures.

Clinical implications

Our understanding of partial foot prostheses is very much in its infancy. Evidence on the topic isn't yet sufficiently developed to answer a range of questions or to make strong recommendations about how specific individuals with PFA can best benefit from prosthetic intervention.

As a more comprehensive body of evidence is developed, clinicians and persons with PFA still need to make decisions about which intervention will be less likely to result in adverse consequences, improve specific aspects of walking or quality of life to name just a few examples. The available evidence offers some guidance to help inform these decisions and an illustrative example can be drawn from the previous section describing changes to the gait of person with PFA.

Clinicians routinely provide below-ankle devices that maintain ankle motion (Condie 1970; Heim 1994; Imler 1985; Lange 1991; Schwindt et al. 1973), which has been assumed to allow propulsion or 'push off' during late stance (Burger et al. 2009; Rubin 1984; Rubin 1985; Rubin and Danisi 1971; Stills 1987). The synthesised evidence (Dillon et al. 2007a) shows that once the metatarsal heads have been amputated, power generation across the ankle is virtually negligible irrespective of the device fitted. Persons wearing below-ankle devices that were designed to allow ankle motion and preserve the ability to generate power at the ankle, showed no greater power generation than did persons using clamshell devices where

ankle motion was eliminated. While a device that allows ankle range of motion may be beneficial in a range of circumstances yet to be investigated, such as descending slopes or rising from a chair, the evidence clearly shows that the power generated at the ankle or push-off during gait will not be improved. Selection of such below-ankle designs should, therefore, be based upon other factors such as cosmesis or the need to prevent ulceration in persons at high risk. Unfortunately, our understanding of some of these broader areas is similarly limited by the sparse number of studies. Nevertheless, decisions about device selection should still be informed by the best available evidence in conjunction with the clinicians' experience and expertise as well as the clients' values (Sackett et al. 1996).

While this article focuses on the evidence that exists around the influence of prosthetic intervention on gait, this is but one small piece of a much larger puzzle that needs to be completed before we can describe the effectiveness of prosthetic intervention in a complete way. It is important that broader considerations about the effects of prosthetic treatment, such as quality of life, remain part of the focus of researchers so that evidence grows in a range of areas related to device effectiveness.

Conclusion

PFA is a common consequence of advanced vascular insufficiency, usually secondary to diabetes and its complications, although it can occur from other causes. PFA affects about 2 per 1000 head of population in industrialized countries making it the most common form of amputation surgery. PFA is associated with numerous complications such as ulceration which can lead to subsequent and more proximal amputation.

While a variety of interventions have been used to manage the partially amputated foot, formally evaluating their efficacy has only recently become a subject of research interest. Investigations have identified a number of abnormal movement patterns consistent with the inability to generate power at the affected ankle joint and loss of effective foot length in many devices – particularly below-ankle devices. A number of compensatory adaptations have been observed, including increased power generation at both hip joints.

The efficacy of prosthetic intervention is becoming better understood as more research is published. Further investigation is required to better understand the influence of prosthetic intervention in a number of areas so that clients and clinicians can make better informed decisions about treatment options.

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Glossary

Centre of Pressure (CoP)

Describes a single point which represents the sum of all pressure over a particular area. This position of this point can be tracked through a gait cycle or with respect to a body segment such as the foot. In this way, it is possible to identify when and how far the CoP has travelled. This is known as the excursion of the CoP.

Contralateral

The opposite side of the body; the opposite limb.

Dorsiflexion

Movement at the ankle joint where the dorsum (top) of the foot moves towards the anterior surface of the tibia (shin).

Experimental study

A type of investigation in which researchers systematically manipulate the experimental conditions to determine whether this affects the outcome.

Ground Reaction Force

Force exerted by the ground on a body in contact with it. For example, a person standing on the ground exerts a force upon it. At the same time and equal an opposite force is exerted by the ground on the person.

Kinematics

Description of movement of body segments without regard for the cause of the movement.

Kinetics

Descriptions of the underlying cause of human movement including: muscle forces, torques.

Marker set

In the analysis of human movement, a set of markers (eg. small spheres of reflective tape) are attached to the key landmarks on the body (eg. top of foot; ankle). Usually there are three markers (set) attached to each body segment. A camera system records the trajectory of these markers which are subsequently used to calculate angles of the limbs in relationship to one another; as an illustrative example.

Moments

Measure of the potential a force has to produce rotation at a joint.

Observational study

A type of investigation whereby individuals are observed and outcomes measured without any intervention.

Plantarflexion

Movement and the ankle joint where the foot moves away from the anterior surface of the tibia (shin); straightening out of the ankle joint; point the foot downward.

Plantarflexor musculature

Muscles that cause plantarflexion movement. In lay terms, these muscles are collectively known as the calf muscles (soleus and gastrocnemius).

Plantar pressure

Pressure experienced by the sole (plantar surface) of the foot.

Power generation

Power is a measure of the rate at which work is done or energy is expended. Power generation reflects concentric muscle activity (muscle contraction where the muscle shortens in length). Power absorption describes eccentric muscle activity (muscle contraction where the muscle gets longer).

Stance (phase)

The period of the walking cycle when the foot is on the ground.

Tarsometatarsal

A partial foot amputation disarticulating the tarsometatarsal joints as described by surgeon Lisfranc.

Transtarsal

A partial foot amputation that divides the talonavicular and calcaneocuboid joints. Also known as a Chopart amputation after the surgeon who pioneered the procedure.

Temperospatial

Collective name for measures of time or duration (temporal) and distance travelled (spatial) as part of human walking. A 'step' for example is a measure of distance covered by successive foot placements.

Walking velocity

Measure of the speed of walking.

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