White Paper

Prosthetic management of partial foot amputations – a literature search and comprehensive management model

Introduction

In June 2021 a post from an O&P practitioner was listed on the O&P list serve[1] asking for recommendations on managing a Chopart (Figure 1) amputation. There were an incredible array of answers including:

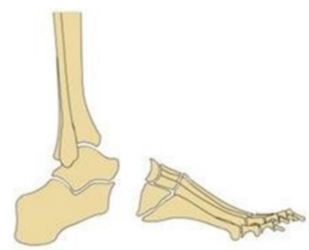

Figure 1

- (Go to) BKA - don't even waste your time
- Gauntlet style AFO
- … abbreviated CROW walker
- Custom molded total contact partial foot orthotic / depth inlay shoe with rocker soles
- Matching shoe for the other side with lift
- Gauntlet style AFO with toe filler, made into a walking boot
- SACH heel and rocker bottom on shoe – soft custom-made silicone foot bed
- Clamshell posterior opening and shoe lift on the other side…
- Start with cowboy boots…

Diversity is a good thing, but these comments offer advice that is contradictory and show a complete lack of consensus on how to manage a relatively common level of amputation. The divergent suggestions triggered a literature search to find data or published direction on how to manage the partially amputated foot. Searches were done on PubMed (www.ncbi.nlm.nih.gov) and Google Scholar (www.Google Scholar) with phrases including "Partial Foot Amputation", "Prosthesis for Partial Foot Amputation", and "Management of Partial Foot Amputations".

Search results

The search uncovered numerous studies including one by Lee in 2020 indicating the risk factors involved in necessitating a partial foot amputation (PFA). Those risk factors include osteomyelitis, peripheral artery disease, chronic kidney disease, ulcer size, and forefoot ulcer location[2]. Martins-Mendes found that there is an independent contribution of diabetic foot ulcer on lower extremity amputation and mortality risk[3]. There are no lack of data on factors leading to PFA.

Nor are there any lack of data on the incidence and prevalence of PFA. In a systematic review to synthesize epidemiological data describing the incidence rate and prevalence of PFA, Dillon et al found that the risk of PFA is significantly greater (about 25 times greater) for people with diabetes. The incidence is (94.24 per 100,000 people with diabetes; 95% CI 55.50 to 133.00) compared to those without (3.80 per 100,000 people without diabetes; 95% CI 1.43 to 6.16). The weighted mean annual incidence rate of PFA was 109.63 per 100,000 people with diabetes[4]. Kaminski found prevalence estimates of 14.4% for foot ulceration and 5.9% for amputation in adults on dialysis[5].

The trend in surgical interventions is an increase in PFA with a corresponding decrease in trans-tibial amputations. Dillon reports that the incidence of transtibial amputation or below knee amputation (BKA) has declined steadily since about the year 2000, and there is some evidence that PFA has increased proportionately[6].

Wound healing is another area where data are readily available. In his study, Zhang found that the reported transmetatarsal amputation (TMA) wound healing rates from multiple series were not good (range, approximately 40–70%)[7]. In the same vein, Dillon reports that partial foot amputation is associated with high rates of complications and subsequent transtibial amputation[8]. No detailed research or analysis was found to identify and define the causes of these complications, other than the assumption that the underlying causes of amputation still exist and may progress post-amputation.

Management of diabetic foot ulcers is broadly covered in literature. Subjects ranging from wearable devices[9] to nutritional interventions[10] to platelet-rich gel treatment[11] to negative pressure wound therapy[12] to telemedicine[13] were readily found. Absent from this search were any findings that discussed alternatives to managing destructive shearing forces that occur within the PFA foot during walking.

Some make the argument[1] that outcomes of PFAs are so bad that it's better to just go straight to a BKA. In 2014 Quigley reported that there is insufficient evidence about differences in quality of life (QoL) between persons with PFA or BKA. Contrary to common belief, the available evidence suggests that QoL may be similar in persons with PFA and BKA[14]. In 2017 Dillon was a bit more pointed. He stated that more distal amputation results in better mobility, improved QoL, and lower mortality. However, PFA has been associated with low rates of healing and complications that often lead to ipsilateral re-amputation[6]. Neither author examined the exact cause of the re-amputations, although increased pressure on soft tissue has been discussed. In 2021 Thorud presented a thorough section on pressure finding that both first ray and TMA amputations lead to higher pressures that could lead to subsequent amputations[15].

The lack of discussion on shearing forces, limb length loss measured from fibular head to floor, or the absence of studies on definitive prosthesis for PFAs is remarkable. In an epic 119-page report, Wang et al listed50 recommendations for managing every aspect of the diabetic foot. Absent is any mention of prosthetic management for the partially amputated foot[16]. Significantly, in that same report, he did suggest that Achilles tendon lengthening can reduce the risk of recurrence of foot ulcers by 75% in 7 months and 52% in 2 years, especially in patients who present with neuropathic forefoot ulcers complicated by a limited ankle dorsiflexion of <5°.

A biomechanical approach

The necessity of a fresh look at managing the partially amputated foot became obvious. A comprehensive model is needed to manage issues that could be contributing to the high failure rates of current methods. The need for a new model is based on widely published data that show that prosthetic outcomes for PFAs were not satisfactory, either from a medical outcome or from a patient satisfaction point of view.

There are two separate but complimentary goals in this model: one is to preserve the residual foot and make sure that the prosthetic intervention doesn't contribute to a subsequent proximal amputation. The second is to restore gait to as close to normal as possible by resolving the fibular head to floor acquired limb length discrepancy and by restoring the propulsive lever arm to minimize shearing forces and gait compensatory mechanisms[17].

Preservation of the residuum involves managing the terrible trio of pressure, friction and shearing forces. It must be noted that even with the best possible prosthetic intervention that it is still possible for vascular disease to progress which could lead to a more proximal amputation. The goal should be to make sure the prosthetic intervention doesn't contribute to a secondary reamputation.

Limb preservation

Pressure is simply defined as force over area. With a PFA the area of the foot is decreased so there has to be an increase in pressure. Data provided by Thorud[15] and others confirm that increased pressure can contribute to soft tissue breakdown of the residuum. Pressure on soft tissue can blanch blood from those tissues leading to cell death and eventual ulcer formation. This increase in pressure makes a custom socket or distal cushion of the entire residuum medically necessary to distribute forces over a larger area.

Friction may be the easiest of the potential destructive forces to manage that can impact the viability of the residual foot. Friction is defined as one body moving against another. Poorly fitted footwear or orthotic/prosthetic interventions that are too large can result in friction that leads to disruption of soft tissue, usually in the form of blisters.

Data on shearing forces were not found in this study. These forces are perhaps the most destructive to the residuum and the hardest to control. Consider the foot as a series of lever arms: the forces of the posterior compartment cross the ankle and control the mid- and forefoot lever arms distal to the ankle. Forces from the anterior compartment cross the ankle and control the rearfoot. When the forefoot is shortened, the power of the calf group overpowers the now too-short residual forefoot lever arm, causing residual bone to move inside the skin, disrupting or shearing connective tissue within the foot. The result of this shearing is the development of calluses. Continued shearing usually results in ulcer formation under the callus, and repetitive ulcer formation usually leads to PFA.

The other consequence of a too-short anterior lever arm is the resultant loss of propulsion. Power crossing the ankle normally propels the foot off the ground. That same power initiates swing during gait. Dillon reported that amputation proximal to the metatarsal heads compromised the normal propulsive function of the foot[18] leading to increased metabolic cost during gait.

Molded plastic AFOs may exacerbate the problem. Vistamehr reports that polypropylene AFOs restrict the ankle range of motion and hinder the generation of propulsion and the regulation of angular momentum in both the frontal and sagittal planes[19].

No amount of cushioning or padding can resolve shearing forces. The only solution to the destructive forces of shearing is to restore the length of the propulsive lever arm. That can be accomplished through the use of a carbon composite AFO that features a full-length footplate and a pre-tibial shell that comes to the height of the tibial tubercle. The footplate and lateral strut act like a spring to load potential energy and then return that energy in the form of motion to help restore the propulsive lever arm. Kaib reported that high-profile prostheses with ventral shell are more suitable to reacquire the lost forefoot lever after Chopart amputation[20].

The same lever arm criteria are required to avoid shearing forces and callus formation on more distal amputations. If callus formation on the distal end of the residuum at any level is an adverse complication that could lead to reamputation, then restoring the length of the propulsive lever arm is the only logical and medically necessary solution.

Gait restoration

There are two issues that need to be addressed in order to restore gait function in the PFA population. The first is to restore the propulsive lever arm – the same lever arm that helps minimize shearing as described above. Mueller reported that power crossing the ankle becomes negligible with any amputation involving the metatarsal heads[21]. The absence of the anatomical propulsive lever arm leads to proximal compensations including trunk sway, hip hiking, excessive trunk torque, shorter sound side step length and shorter involved side time in single limb stance. Restoring the propulsive lever arm helps minimize compensatory mechanisms and allows the trunk to "go along for a free ride", making gait more stable and efficient.

Figure 2. Chopart with 0° CIA, bulbous heel

Recently Anderson published a case study of a bilateral PFA patient with recurrent ulcer formation. After just one week with (carbon composite AFO) prostheses, the patient reported marked improvement in quality of life due to improved walking ability on level and uneven terrain, marked improvement in confidence, and reduced pain[22].

The second issue to help restore gait is to manage the limb length deficit that is acquired secondary to PFA. The literature search did not find any reference on this subject, but it is commonly seen in clinical practice. The extreme of this presentation occurs with a Chopart amputation where the weightbearing patient presents with a large bulbous heel (figure 2). The rigid architecture of the mid- and forefoot support the ankle in its neutral posture. The loss of that rigid bone structure leads to the ankle dropping into plantarflexion. Because there is no longer a mid- or forefoot to use as reference, the only anatomical reference left to determine ankle neutral is the calcaneus. With the ankle at its neutral posture the neutral calcaneal inclination angle (CIA) is 18° to 25° (figure 3)[23]. Lower angles are generally associated with more pronated feet and higher angles are usually associated with more supinated feet.

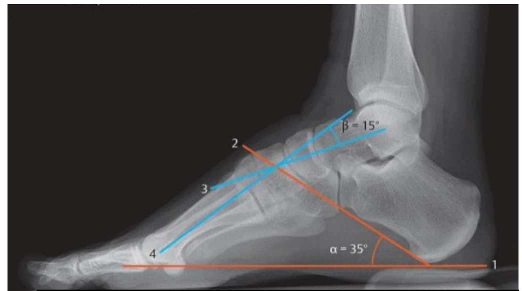

Figure 3. Neutral CIA

With the Chopart related bulbous heel now posterior to the tibia instead of underneath it, there has to be a resultant limb length loss associated with that posture. Based on limited clinical experience and physical models, one can anticipate an acquired limb length loss for a Chopart amputation – measured from fibular head to floor – of 2 to 3 cm.

That finding lead to discovering if there is also limb length loss associated with more distal amputations. Using physical models and limited clinical findings, there is a high probability of limb length loss with any amputation proximal to the metatarsal heads. A loss of .75 to 1.25 cm can be anticipated with a TMA, while a limb length loss of 1.25 to 1.5 cm can be anticipated with a Lisfrank amputation. Restoring acquired limb length is necessary to help restore pelvic balance and symmetrical gait in the PFA population.

The proposed prosthetic intervention is designed to manage pressure, friction and most importantly shearing forces to minimize callus and therefore ulcer formation. It is also designed to restore limb length and restore propulsion during gait, thereby minimizing proximal compensations and the metabolic cost of gait.

Intervention model

Before creating a custom prosthesis, an assessment is made to determine available ROM at the involved side ankle. That is done by the patient standing unshod on the residuum on the end of a board. The other end is then lifted to determine available ankle ROM. A non-weightbearing slipper cast or scan is used to capture the residual foot and a positive model is made from that.

It is suggested that the interface liner be contoured over the model using 1/8" material similar to Impression Puff 25 durometer EVA. The "socket", more accurately the "distal cushion", is then formed using 1/8" black co-poly. The plantar anterior aspect of this shell is then posted to restore the CIA toward a more neutral posture in the sagittal plane, matching the sound side as much as possible. The posterior aspect can be used to post for excessive calcaneal ROM in the frontal plane just as one would post a foot orthotic.

Figure 4. Custom partial foot prosthesis

A prefabricated heavy-duty carbon composite AFO (figure 4) is then prepared by adding an interface liner to the inside of the pretibial shell. The modified socket is then placed on the footplate and aligned to the pretibial shell so there is equal pressure from top to bottom of the tibia [17]. Once that is established, the filler prosthesis is added to the footplate anterior to the socket using material similar to 1” Microcell Puff® Lite. The prosthesis is then shaped to match the sound side length, width and height.

The prosthesis is placed in the patient’s footwear and then they put their shoes on. The shoes should be well constructed on a neutral last with as firm a sole material as possible. Avoid soft cushiony soles as this takes away from the support of the prosthesis and makes gait less stable.

In limited experience many patients will adapt to the prosthesis in just a few minutes. For others it may take some time – hours or even days – to acclimate to the new intervention. If the occasional patient has residual gait deviations in the new device, gait training by a physical therapist is sometimes recommended.

Future research

Future research could focus on designs to study PFA patients who are failing in conventional interventions and who are then switched to this proposed design. The study should include both the medical presentation of the residuum before and 6 weeks after switching and include patient reported outcomes on quality-of-life issues. As few individual clinics see enough patients to gain numbers that are statistically significant, the study could be done to standard protocols by numerous clinics in larger organizations.

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About the author

Robert Meier, CO, has been active in the fields of orthotics, therapeutic exercise, and biomechanics since 1978, and has been conducting education programs since 1982. His special interest is in applied closed chain biomechanics and muscle function. He has developed and taught numerous courses across North and South America, Australia and Europe on gait assessment, rehabilitation and orthotics. He holds six patents applying functional biomechanics to lower extremity and spinal interventions.

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