The Biomechanics and Management of Apropulsive Gait

Here's how managing apropulsive gait may improve outcomes.

BY ROBERT MEIER

Introduction

A recent search on PubMed for "Apropulsive gait" yielded zero results. A Google Scholar search yielded 16,300 references including "propulsive" and "gait" used in the same sentence, but only one reference[1] used the term, defining it as an absence of heel-to-toe gait. Another reference used the term only to remark on the absence of the term in literature.

Those findings beg the question, "Why read an article about a subject not mentioned in literature?" The answer is simply that a significant percentage of patients seen by foot and ankle surgeons are, in fact, apropulsive. Once that is recognized and appreciated, managing those patients becomes more productive and therefore gait outcomes become more rewarding for both patient and physician.

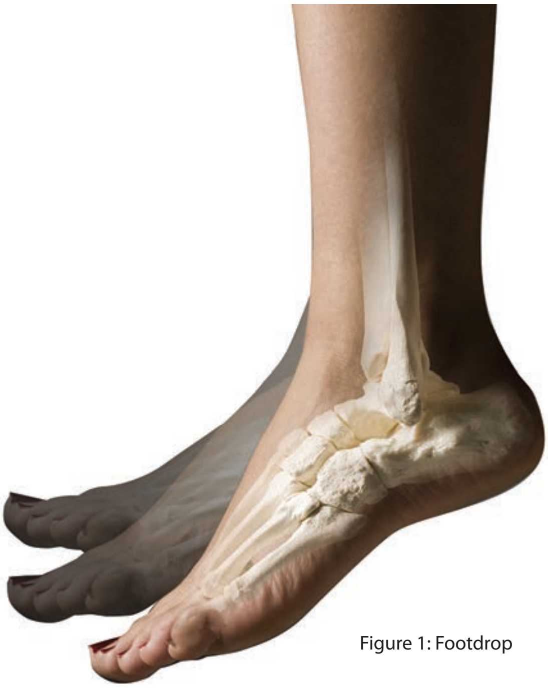

Figure 1: Footdrop

Definitions

In her 2010 book *Gait Analysis*[3], Jacquelin Perry lists "propulsion" as the first of four key components of gait. It is defined as concentric power from the posterior compartment crossing the ankle and propelling the foot off the floor. In addition, that same power propelling the foot off the floor helps initiate the swing phase of gait. It can be defined as the ability to do a single limb heel rise. Therefore "apropulsive gait" is a lack of power crossing the ankle so that proximal frontal plane compensatory mechanisms must lift the foot off the ground, while secondary transverse plane compensatory mechanisms must initiate swing. The patient with apropulsive gait will present with a limp indicating a higher metabolic cost of gait leading to a shortened distance capacity.

Neuromuscular Deficits Resulting in Apropulsive Gait

Apropulsive gait occurs when communication between the motor cortex, spinal interneuron, and muscles of the calf group is disrupted, resulting in a lack of concentric power crossing the ankle (Figure 1).

Neuromuscular deficits typically lead to footdrop, but not all footdrop patients have apropulsive gait. *"Simple footdrop"* can occur when ankle dorsiflexors are dysfunctional, but ankle plantar flexors are still intact and functional. Some spinal injuries can lead to this condition, as will a disruption of the common peroneal nerve just distal to the fibular head. This patient typically presents with steppage gait defined as gait with excessive hip and knee flexion on the involved side to create toe clearance during swing. The trunk remains relatively stable, there is little to no increase in transverse plane stress on the sound side, and there is minimal increase in the metabolic cost of gait. AFO intervention for this patient should help pick up the foot during swing without inhibiting power crossing the ankle.[4]

The second category is *"complex footdrop"*, defined as

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dysfunction of ankle plantar flexors leading to footdrop, associated with concurrent dysfunction of ankle plantar flexors leading to apropulsive gait. CVA, MS, and over 50 other neuromuscular conditions are common causes of complex footdrop and apropulsive gait. This patient typically presents with hemiplegic gait involving footdrop plus a lack of propulsion, leading to multiple predictable compensatory mechanisms including shorter involved side time in single limb stance, shorter sound side step length, trunk sway, hip hike and excessive torque in the trunk and pelvic girdle. The metabolic cost of gait is significantly higher leading to limited distance capacity for these patients. Restoring propulsion along with helping pick the foot up during swing are the primary goals for those patients.

Lisfranc and Chopart level amputations lead to 100% loss of the propulsive lever arm.

Soft Tissue Dysfunctions Resulting in Apropulsive Gait

Soft tissue injury is the second condition leading to apropulsive gait. Disruption of muscle, tendon and ligament structures occurs when ordinary stress crosses tissues that are deficit secondary to disuse atrophy or are weakened due to metabolic changes. Disruptions can also occur when extraordinary stress cross healthy tissues that have not been conditioned to withstand that much force. When a patient presents with 10/10 pain secondary to the diagnosis of Insertional Achilles Tendinopathy (IAT) (Figure 2), that involved side is not propulsive because it hurts too much to contract the calf group to plantarflex the ankle for propulsion. It even hurts too much to allow the tibia to progress past the foot on the ground, creating ankle dorsiflexion stretch on the structure. Other structures commonly seen in foot/ankle clinics that can lead to apropulsive gait include posterior tibialis tendon dysfunction (PTTD), leading to adult acquired flatfoot (AAF) deformity, mid-portion Achilles disruptions, and plantar fasciitis.

Pain is the primary symptom of soft tissue dysfunction. Compensations can include less time in weight-bearing and shorter sound side step length combined with a lack of propulsion leading to the appearance of hemiplegic gait. Gait associated with Achilles disruptions typically present as step-to gait to limit the stress of stretch on that structure in dorsiflexion. Either presentation can lead to significant limitations in distance capacity and activities of daily living.

Figure 2: IAT (Insertional Achilles Tendinopathy)

Immobilization has been the primary means to manage the acute phase of these injuries to “give it time to heal”. However, data do not support that practice. Several authors have come to the same conclusion that short-term voluntary immobilization is associated with atrophy and a diminished capacity of the muscle to develop maximal voluntary force.[5,6,7,8,9] Structures that were too weak to handle stress are made weaker with immobilization. The strength of a maximal voluntary contraction is reduced by 24% after just 2 weeks of immobilization.[9] Evidence-based guidelines on the use of immobilization in the management of common acute soft-tissue injuries do not exist.[5] There is a definite trend away from immobilization and towards a more evidence-based controlled stress approach to managing soft tissue dysfunctions.[10,11]

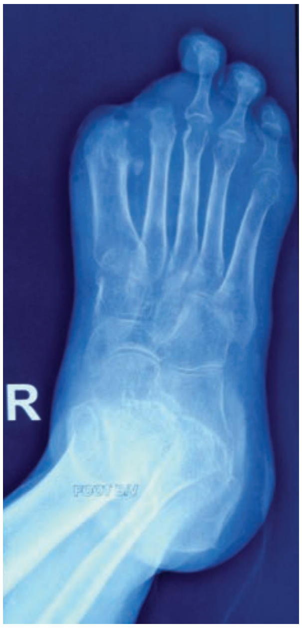

Figure 3: X-Ray Partial Foot Amputation

Partial Foot Amputations Resulting in Apropulsive Gait

Partial foot amputation (Figure 3) is the third category of patients who present as apropulsive. For this cohort, it’s not a lack of concentric power or pain that limits propulsion but the lack of a propulsive lever arm. At the transmetatarsal level, data show greater than a 75% loss of power crossing the ankle, not because of dysfunction of the calf group but because of the shortened propulsive lever arm[12]. Lisfranc and Chopart level amputations lead to 100% loss of the propulsive lever arm.

Symptoms related to partial foot amputations usually present as balance deficits, pelvic obliquities secondary to acquired limb length loss on the involved side, slower walking speeds and pain at the distal residuum. That pain can also be a significant symptom on more distal amputations such as great toe disarticulations and TMAs when shearing forces cause disruption of

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connective tissue between bone and skin leading to callus formation. Compensations mimic hemiplegic gait when the foot needs to be lifted off the floor (hip hike and trunk sway) and swing needs to be initiated (torque through trunk and pelvic girdle down into the sound side limb). This gait pattern is associated with a high metabolic cost during gait leading to limited distance capacity.

If a partial foot patient doesn't have the capacity to propel the foot off the floor, one of the design criteria for prosthetic intervention should include the concept of adding energy return capabilities into the prosthesis. Because shearing leading to callus formation is caused by a too-short lever arm, no amount of padding will prevent that formation. The only solution to callus formation and subsequent ulcer formation under the callus is to restore the length of the propulsive lever arm.

ERAFOs are available from several sources as sized prefabricated devices, or if necessary, they can be custom made to a model of the patient.

Managing Apropulsive Gait

Energy Return AFOs (ERAFO) (Figure 4) are hybrid Carbon Fiber AFOs (CFAFOs). They are carbon *composite* devices that are engineered to help pick the foot up during swing. They also load potential energy in the 2nd rocker as the tibia progresses over the foot that's fixed to the ground and return that energy in the 3rd and 4th rockers, augmenting the function of the calf group to help propel the foot off the ground and initiate swing.[13,14,15] In doing so, they help reduce or eliminate the proximal compensatory mechanisms associated with all three causes of apropulsive gait.

ERAFOs are available from several sources as sized prefabricated devices, or if necessary, they can be custom made to a model of the patient. The ideal design criteria include an energy return footplate that mimics the function of the foot, an open calcaneal design to allow the normal biomechanical transition from supination to pronation and back again, an energy return lateral strut to allow the foot to roll away from the strut at weightbearing, and a broad pre-tibial shell to distribute the forces of the lever arms over a broad area to reduce pressure on soft tissue. The thin material used to manufacture these devices usually means that patients can normally wear their usual shoe size versus the need to upsize one side for a plastic AFO.

ERAFOs require customization by the provider. To restore propulsion, it is important that these ERAFOs are tuned to the functional needs of each patient. Tuning involves matching the support levels and energy return characteristics of the device to the functional needs of each patient.

The more complete systems on the market have devices more appropriate for smaller framed persons or patients with minimal functional deficits. They also supply a range of heavier duty devices for persons who have significant functional deficits and may exceed 30 or even 35 BMI. Matching the support and energy return characteristics of the device to the functional needs of the patient is critical to optimize healing and functional outcomes.

Other tuning considerations include managing obvious foot biomechanical variances from normal with custom foot orthotics. Shoes worn with these devices should feature firm high durometer soles and a rocker toe. Check with the manufacturer for patient education considerations.

Expected ERAFO Outcomes

Neuromuscular Deficits: For neuromuscular deficit footdrop patients, ERAFOs not only pick up the foot during swing, but more importantly augment the function of the ankle plantar flexors by helping to propel the foot off the floor. This energy return capability helps balance the spatial/temporal parameters between involved and uninvolved side making gait more symmetrical and fluid. There are usually significant improvements in static and dynamic balance and in distance capacity. Data show a decrease in energy cost of walking and an increase in walking speed, without introducing any kinematic changes in the knee and hip.[16] An Ohio State University study of 123 patients reached the conclusion that anterior shell CFAFOs should be considered for most neuromuscular patients with distal leg weakness.[17]

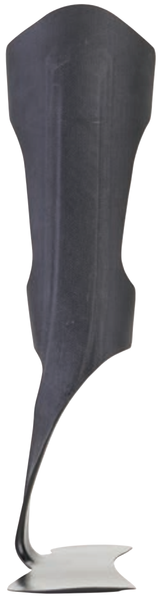

Figure 4: ERAFO (Energy Reflecting Ankle Foot Orthosis)

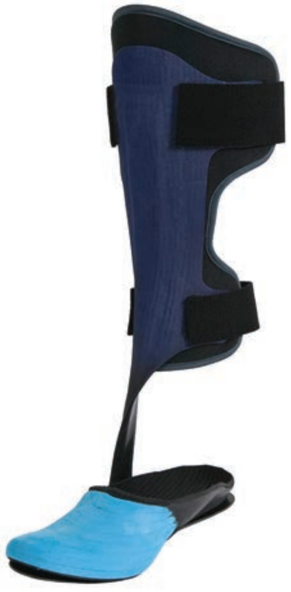

Figure 5: Partial Foot Prosthesis

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Soft Tissue Dysfunction: Soft tissue structures can be injured if there is normal stress across a weak structure, or if there is excessive stress across a normal structure. Immobilization makes those structures even weaker, furthering the chance for future injury. ERAFOs restore propulsion, reduce stress on soft tissue structures, set limits to end range motion, protect the injured structures and allow healing to occur in a more protected environment that avoids the disuse atrophy and the delayed healing that is associated with immobilizing devices. Pain relief can usually be seen immediately upon fitting the device, allowing for fewer inhibitions to gait.

Partial Foot Amputation: ERAFOs used in apropulsive partial foot amputation applications are no longer considered AFOs but are used as the composite superstructure that is the framework for the partial foot prosthesis (Figure 5). The prosthesis includes a custom socket for the residual foot and a filler prosthesis distal to the socket to help maintain the integrity of the shoe upper. The socket is designed to manage friction and pressure to help maintain the integrity of the residuum, while the superstructure is designed to replace the lost lever arm of the foot to manage shearing forces to control or eliminate the shearing forces that lead to disruption of connective tissue within the foot that leads to callus formation. Those same lever arms of the superstructure also help restore propulsion to minimize proximal compensatory mechanisms so gait becomes more natural, symmetrical, stable, and energy efficient.

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Summary

By restoring propulsion, ERAFOs can restore more normal propulsion to gait for patients who are challenged with functional instabilities and distance limitations. Patients who are apropulsive secondary to neuromuscular deficits can be more active and independent with the restoration of propulsion as a component of gait. Soft tissue dysfunction patients can have more normal gait as the injury is allowed to heal in a more appropriate environment. And partial foot patients can improve their capacity for ADLs as the foot is preserved and gait is restored. **PM**

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