Diagnosing and Treating Deficits in Propulsion to Improve Walking After Stroke: Clinical and Technological Advances

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Course Objectives
1. Recognize the importance of symmetrical propulsive force generation during walking.
2. Identify neuromotor deficits underlying impaired propulsive force generation during hemiparetic walking.
3. Select treatment approaches to target deficits in propulsive force generation.
4. Consider how rehabilitation technology can augment therapies targeting deficits in propulsion.

Course Content
- For individuals poststroke, propulsive force generated from the paretic limb has been shown to correlate to walking speed such that walking faster requires greater limb propulsion; however, individuals poststroke tend to increase walking speed primarily by increasing nonparetic limb propulsion. Treadmill-based gait training is able to reduce the reliance on the nonparetic limb's generation of propulsive force to increase walking speed.
- Although walking speed is a key outcome hailed as the 6th vital sign, poststroke deficits in long-distance walking function have a stronger link to reduced ambulatory activity in the community. When asked whether walking faster or walking farther is more important to getting "out and about", individuals poststroke identify deficits in walking farther as more limiting. It has been shown that paretic propulsion is highly associated with the distance walked during the 6MWT—a key determinant of community walking activity—even when accounting for other commonly targeted gait variables such as spatiotemporal asymmetry and ground clearance kinematics (knee and ankle flexion).
- Propulsive deficits may be useful in distinguishing unique motor control deficits. Individuals who produce less propulsion from the paretic leg demonstrate higher flexor activity early in the gait cycle, take longer steps with the paretic leg, and often lack adequate hip extension to achieve a biomechanical position to produce propulsion. This hip extension in terminal stance is critical in propulsion and the amount of propulsion increases when hip extension is selectively increased. In contrast, a portion of post-stroke patients achieve propulsion from the paretic leg that exceeds that from the non-paretic leg, but this comes at the cost of overall decreases in full-body acceleration and inefficient transitions from stance to swing.
- There are a variety of ways to measure propulsion—e.g., peak propulsive forces and area under the curve (impulse) of propulsion—quantifying paretic limb propulsion as the percentage of overall propulsion performed by the paretic and nonparetic legs is useful in identifying neuromotor performance. This measure of propulsion relates to both walking speed and severity of the stroke (Fugl-Meyer score). Moreover, this measure can serve as a marker for recovered gait (in terms of force production) as opposed to traditional measures that are not able to discriminate from compensatory strategies. Paretic propulsion may be used as an outcome measure for a variety of interventions (body-weight supported treadmill training, strength training, and aerobic training) and may be an important marker in responder vs. non-responder analyses.
Walking speed is a common stratification criterion in clinical intervention studies, with outcomes often reported across speed-based subgroups. However, we have shown that this may not be an optimal approach for dealing with the problem of poststroke heterogeneity. Indeed, there is variability in biomechanical performance within speed-based subgroups (i.e., individuals walking at the same speed present with different walking patterns). This reduces the utility of using speed as a prognostic indicator of intervention efficacy. It has been shown that by accounting for both walking speed and propulsion, prognostic power can be increased.

We know that limb propulsion is important for mediating O2 cost of walking. It has been shown that unilateral propulsion assistance/resistance has a profound effect on metabolic cost (in both individuals post-stroke as well as unimpaired controls). This clinically applicable approach may enable training to continue longer (i.e., propulsion assistance) or promote greater self-initiated propulsive forces (i.e., propulsion resistance). Individuals post-stroke appear to exhibit a propulsive reserve when walking at their comfortable gait speed. In response to an impeding force, there exists the capacity to increase paretic propulsion. Although the kinematic/kinetic mechanism underlying this change remains unclear, this exciting observation suggests that a reserve can be exploited.

There is mounting evidence that many individuals, after succumbing to reduced propulsion, retain a neuromuscular reserve for enhancing push-off intensity during walking that goes underutilized for reasons that are poorly understood. These ‘propulsive reserves’ can be accessed through the use of visual biofeedback. Studies in older adults have thus far targeted enhancements in propulsive force at the limb level, ankle power at the joint level, and plantarflexor EMG at the muscle level during push-off, with exciting and translationally relevant results.

Our understanding of what governs push-off intensity, or the available reserves thereof, during walking at preferred speeds remains fundamentally incomplete. A more functional assessment of propulsive reserves during the push-off phase of walking could empower the discriminate prescription of gait interventions that seek to enhance propulsion. A ramped impeding force protocol applied during walking via a custom motor-driven force field is now providing new and exciting insight into the factors governing the functional utilization of propulsive capacity during human walking, and changes thereof due to aging, injury, and disease.

Recent advances in dynamic ultrasound imaging are empowering the simultaneous in vivo assessment of muscle contractile and tendon tissue dynamics governing propulsive power generation, and declines thereof due to aging and gait pathology such as stroke. For example, evidence suggests that adhesions within the Achilles tendon of older adults unfavorably couples the gastrocnemius and soleus muscles – an effect that positively correlates with declines in ankle moment, ankle power, and ankle work during push-off. The potential use of dynamic ultrasound imaging is gaining popularity in the tailored prescription of wearable devices designed to augment the mechanical output of the plantarflexor muscle-tendon units (i.e., robotics/exoskeletons) – an approach that aims to optimize our efforts to restore propulsion and reduce metabolic energy cost during walking.

While the force-generating capacity of the plantarflexors is an important determinant of propulsive force generation during walking, it is deficits in the activation of the plantarflexors that most contributes to reduced propulsive force generation during hemiparetic walking. Using supramaximal electrical stimulation testing of the plantarflexors, it has been shown that deficits in activation, and not strength (volitional or capacity), underlie impaired paretic propulsive function during poststroke walking. Interestingly, we have seen that walking with functional electrical stimulation (FES) assistance to the plantarflexors increases corticomotor input to the plantarflexors in follow-up testing.

An emergent propulsion-targeting intervention is the FastFES locomotor program. FastFES training is the combination of fast treadmill walking with plantarflexor FES to target concurrently hip extension and
plantarflexor function. This combination promotes the translation of increased plantarflexor force into propulsion by facilitating a better trailing limb position during FES delivery. Single-session studies validate this biomechanical framework and a 12-week training intervention centered on FastFES has been shown to produce therapeutic improvements in propulsion and increase long-distance walking speed without increasing the energy cost of walking.

- Attempts to enhance limb propulsion via an exoskeleton-induced increase in ankle power have yielded mixed results. Recent studies show little change in metabolic expenditure, although recent work with soft robotics appears promising. Differences in control algorithms and study design are important considerations that may influence outcomes.
- Soft robotic exosuits targeting paretic propulsion and ground clearance can produce immediate improvements in propulsion, reduce the energy cost of walking, reduce swing phase compensations (hip hiking and circumduction), and increase walking speed and distance. They are compatible with gait training in free-living settings and can replace the passive ankle-foot orthoses commonly prescribed today.

**Course References**


