The influence of passive hydraulic prosthetic ankle-feet on decline and level ground walking

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Clinical Question: Do passive hydraulic ankles (PHA) improve walking mechanics and reduce distal tibial stress across different slopes in individuals with transtibial amputation (TTA) compared to non-hydraulic ankles?

Background: Passive hydraulic ankles may improve walking for people with an amputation by enabling a smoother transition from initial contact through midstance. This transition may be measured as the movement of the center of pressure. During walking with passive prosthetic feet, the center of pressure stops moving anteriorly and briefly moves posteriorly during loading response/midstance, different from what is seen in able-bodied individuals.[1] On decline surfaces in particular, transmission of these center of pressure deviations through the lower limb may contribute to the increased stresses at the distal residual limb relative to level ground walking,[2] increasing risk of skin breakdown,[3] and deep tissue injury.[4] Increased energy dissipation via passive hydraulic ankle systems mounted in series to passive energy storing and returning (ESR) feet may address these concerns. Outcome measures which could characterize improvement in walking mechanics and distal tibial stresses with use of passive hydraulic ankles include: minimizing posterior center of pressure displacement,[1,5,6] increasing self-selected walking speed (SSWS), increasing prosthetic ankle-foot negative work (i.e. the energy absorbed by the ankle-foot complex), and minimizing peak internal stress at the distal tibia.[7] The purpose here was to evaluate prior research studies that characterized these four outcome measures between prosthetic ankle-feet with and without passive hydraulic damping on various slopes.

Search Strategy:
Databases Searched: Google Scholar, PubMed, CINAHL
Search Terms: ("transtibial" OR "trans-tibial" OR "Below-Knee" OR "below knee" OR "BK") AND (ankle) AND (hydraulic)
Inclusion/Exclusion Criteria: Inclusion: 2000 to present, English, peer-reviewed journal articles

Synthesis of Results: Six studies involving 3-20 participants with unilateral TTA were identified that compared passive hydraulic ankles mounted to low profile carbon fiber feet with multi-axial (MA) or ESR feet. Two studies on level ground found significantly decreased posterior center of pressure displacement with passive hydraulic ankles relative to MA/ESR feet suggesting a smoother rollover with a passive hydraulic ankle.[6,8] On level ground, mean SSWS showed a small but statistically significant increase for the passive hydraulic ankle-foot conditions of 0.05-0.09 m/s in three studies,[5,6,8] whereas another study demonstrated a decrease, albeit not statistically significant, in SSWS of ~0.05 m/s.[9] However, these changes were all below the minimal detectable change in SSWS of community dwelling older adults (0.11 m/s) and may not be clinically relevant.[10] On level ground in early stance, and decline surfaces throughout stance, prosthetic ankle-foot negative work was significantly larger for the passive hydraulic ankle-feet vs. ESR feet, indicating passive hydraulic ankle-feet dissipate more energy than prosthetic feet with rigid or elastic ankles.[5,11] Peak internal distal tibial stress was significantly lower when walking with the passive hydraulic ankle-feet relative to ESR feet on both level ground and declines,[7] suggesting passive hydraulic ankles may lower risk of residual limb injury.

Clinical Message: Findings suggest passive hydraulic ankles may improve smoothness of foot rollover and reduce risk of stress related residual limb injury, potentially mediated by increased energy dissipation. Such behavior may be especially important for walking on declines, but perhaps less so for uphill walking, where energy generation is a primary goal. The influence of passive hydraulic ankles on SSWS is likely not clinically significant. Irregularities in statistical analysis, lack of walking speed normalization, lack of blinding to prosthetic ankle-foot type, there being only two studies on sloped surfaces, and the fact that 4 of the 6 articles evaluated were from the same research group are major limitations. Although outside the scope of the selected outcome measures, readers are also referred to a study comparing additional kinetic, kinematic, and subjective outcomes on slopes with and without a passive hydraulic

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ankle.[12] Future work in more controlled environments, such as prosthetic test beds,[13] may be informative in examining the effects of increased damping behavior of prosthetic ankle-feet, and alternative.

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Evidence Table

	De Asha et al., 2013[8]	De Asha et al., 2013[5]	De Asha et al., 2014[6]	Ko et al., 2016[9]	Portnoy et al., 2012[7]	Struchkov and Buckley, 2015[11]
Population	20 active people with unilateral TTA. >2 years post	8 active males with unilateral TTA. >2 years post	11 active people with unilateral TTA. >2 years post	3 males with unilateral TTA, all independent walkers	9 active males with unilateral TTA. >5 years post	9 males with unilateral TTA (>K2). >2 years post
Study Design	Crossover	Crossover	Crossover	Crossover	Crossover	Crossover
Intervention	Echelon™ PHA-foot & habitual MA/ESR foot with rigid or elastic ankle	Echelon™ PHA-foot & rigidly attached habitual Esprit™ ESR foot	Echelon™ PHA-foot & rigidly attached habitual MA/ESR foot	Elan™ microprocessor hydraulic ankle-foot & Echelon™ PHA-foot & microprocessor Proprio Foot™ & habitual ESR foot	Echelon™ PHA-foot & habitual ESR foot (3 Trias, 1 Venture, 2 TruStep, 1 C-Walk, 1 Pathfinder, 1 Esprit)	Active & inactive (PHA) Elan™ microprocessor hydraulic ankle-foot & habitual elastic ankle-Esprit™ ESR foot
Comparison	People with TTA using a PHA-foot v. habitual prosthetic ankle-foot	People with TTA using a PHA-foot v. habitual prosthetic ankle-foot	People with TTA using a PHA-foot v. habitual prosthetic ankle-foot	People with TTA using a PHA-foot v. microprocessor ankle-foot v. microprocessor hydraulic ankle-foot v. habitual prosthetic foot	People with TTA using a PHA-foot v. habitual prosthetic ankle-foot	People with TTA using an active microprocessor hydraulic v. PHA-foot v. habitual prosthetic ankle-foot
Methodology	Subjects walked at SSWS on a level walkway. Motion capture/force plate data collected	Subjects walked at self-selected slow, normal, and fast speeds on a level walkway. Motion capture/force plate data collected	Subjects walked at SSWS on a level walkway. Motion capture/force plate data collected	Subjects walked at SSWS on a level walkway. Motion capture/force plate data collected	Subjects walked at SSWS on a level paved surface, grass, ascending/descending stairs/slopes. Distal tibial stress estimated from residual limb pressure sensors	Subjects walked at SSWS on a 5° decline walkway. Motion capture/force plate data collected
Outcomes	Posterior prosthetic foot center of pressure displacement. SSWS	Negative prosthetic ankle-foot work. Intact and affected side joint moments, powers, work. SSWS	Posterior prosthetic foot center of pressure displacement. Temporospatial measures	Prosthetic/intact ankle, knee, and hip angles, moments, powers. SSWS	Peak, root mean square, and loading rate of internal von Mises stresses at distal tibia calculated with a simplified mathematical model.	Prosthetic ankle-foot negative work. Time to prosthetic foot flat
Key Findings	PHA (v. habitual) feet significantly reduced posterior center of pressure displacement, and resulted in significantly higher SSWS (1.17 v. 1.12 m/s)	PHA (v. ESR) feet significantly reduced prosthetic ankle-foot work in early stance at all speeds, and resulted in significantly higher "normal" SSWS (1.18 v. 1.09 m/s)	PHA (v. habitual) feet significantly reduced posterior center of pressure displacement, and resulted in significantly higher SSWS (1.22 v. 1.14 m/s)	PHA (v. ESR) feet resulted in insignificantly lower SSWS on both the intact (136.4 v. 137.5 cm/s) and affected (124.4 v. 129.7 cm/s) sides	PHA (v. ESR) feet resulted in significantly lower peak stresses and loading rates across all terrains	Significantly more ankle-foot negative work performed by microprocessor hydraulic vs. PHA vs. ESR feet over all stance

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Study Limitations	No blinding to prosthetic ankle-feet. No speed normalization	No blinding to prosthetic ankle-feet. Work only calculated from sagittal plane	No blinding to prosthetic ankle-feet. No speed normalization	No blinding to foot type. No kinetic or kinematic statistics. Small sample size	No blinding to prosthetic ankle-foot type. Potential for inaccuracies in modeling and pressure sensor placement. Degree of slope not presented.	Only blinding to whether microprocessor foot was active/inactive