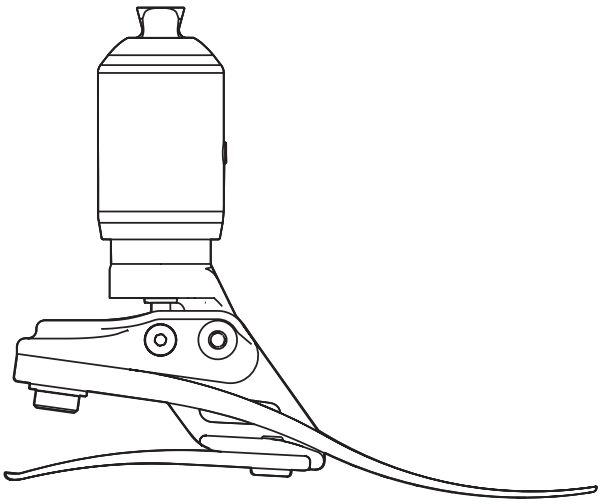


Clinical Studies Compendium

Hydraulic Ankle-Foot Edition 3 (2011-2020)

Blatchford

Foreword

This third edition compendium provides a summary of the scientific studies relating to Blatchford's hydraulic ankle-foot products up to 2020. As such, it acts as a reference for patients, clinicians and health care providers, in order to help them make the most informed decision regarding their prescription. Since the release of the previous compendium edition in 2014, the amount of new evidence for hydraulic ankles has grown significantly. This compendium includes 23 peer-reviewed journal publications describing the clinical benefits of hydraulic ankle technology, as well as nine key conference abstracts. The summaries and reports have been written to provide a concise overview of each research study. For a more detailed report and analysis of findings, the reader is directed to the original authored and published articles.

What's new?

- **Microprocessor-Controlled Hydraulic Ankles**

  Prosthetic microprocessor-control hydraulic ankle function was introduced in 2011 when the Elan was released. Later, in 2015, this technology was incorporated into Linx – the world's first fully integrated limb system. Whether walking uphill, downhill or quickly along level ground, sensors within the limb recognise the situation and alter the levels of plantarflexion and dorsiflexion hydraulic resistance and knee control accordingly. While retaining all the proven patient benefits reported with passive hydraulic ankles (e.g. increased swing clearance, reduced interface pressure), new studies have shown further biomechanical benefits with the addition of microprocessor-control.

- **Hydraulic Technology for Lower Mobility Amputees**

  There is growing evidence in the prosthetics field that lower mobility patients benefit greatly from more advanced technology. Avalon^{K2}, a hydraulic ankle designed for K2 biomechanics, has been the subject of four scientific journal articles in recent years, which reported improved performance and satisfaction among this patient group, compared to non-hydraulic alternatives.

- **Further Evidence**

  In addition to these new areas of study, the supporting evidence for Avalon, Echelon and Elan continues to grow (see graph opposite). Notable new findings compared to rigidly-attached prosthetic feet include improved energy efficiency during walking, greater adaptability to slopes and cambered walking surfaces and a reduction in peak pressure under the sound foot.

Evidence Summary - Established Benefits

Current studies highlight the potential patient benefits of using hydraulic ankles. These benefits occur in numerous areas that are known to be problematic for amputees.

Loading Symmetry

More even weight bearing between healthy and prosthetic limbs

Lower risk of developing osteoarthritis or lower back pain

Energy Expenditure

Less tiring to use

Less demand on the healthy limb

Pressure

Less pressure on residual limb

Less pressure under the healthy foot

Protects against skin breakdown

Falls Risk

Toe clearance is increased when swinging through – less chance of tripping

Fewer trips means fewer falls

Better balance when standing on uneven ground or slopes

Gait Quality

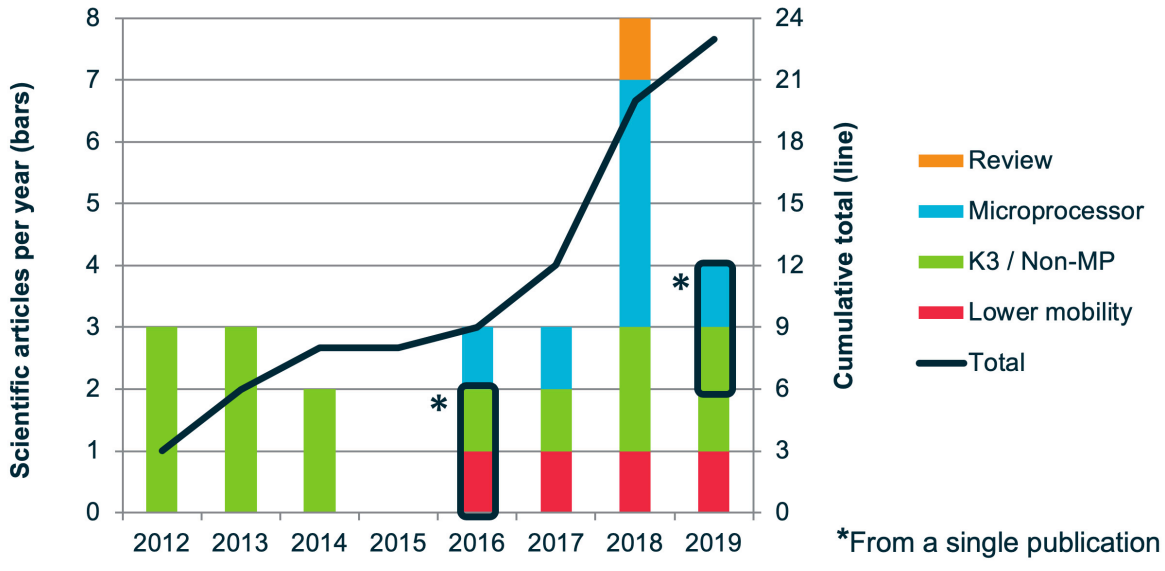
Faster walking speeds

Improved posture

More natural walking over sloped or uneven ground

User Satisfaction

Higher patient satisfaction scores for both low and high mobility amputees



*From a single publication

Studies Overview

		Device type		Activity level		Amputation level			Activity type					
		MPC hydraulic	Passive hydraulic	K3-4	K2	Trans-tibial	Trans-femoral	Bilateral	Level ground	Uneven ground	Sloped ground	Stairs	Standing	Community living
Wurdeman	2019	•	•	•	•	•	•	•						•
McGrath	2019		•		•	•								•
Askew	2019		•	•		•			•		•			
Bai	2018	•	•	•			•				•			
Kannenberg	2018	•	•	•	•	•	•	•	•	•	•	•	•	•
McGrath	2018		•	•	•		•				•		•	
McGrath	2018	•	•	•		•					•			
Abdulhasan	2018	•		•			•				•			
Moore	2018		•	•		•	•		•					
Barnett	2018		•		•	•			•					
Alexander	2018	•		•			•		•		•			
Bai	2017		•	•			•		•	•				
Dotan-Moram	2017	•	•	•		•			•		•			
De Asha	2017	•		•		•			•					
Moore	2017		•		•	•	•	•						•
Struchkov	2016	•	•	•		•					•			
Moore	2016		•	•	•	•	•	•	•					
De Asha	2014		•	•		•			•					
Johnson	2014		•	•		•			•					
De Asha	2014		•	•		•	•		•					
Alexander	2014	•	•	•			•		•		•			
De Asha	2013		•	•		•			•					
Sedki	2013		•	•		•	•	•						•
De Asha	2013		•	•		•			•					
Kristal	2012		•	•		•			•			•		
Erler	2012		•	•	•	•			•				•	
Portnoy	2012		•	•		•			•	•	•	•		
De Asha	2012		•	•		•			•					
Siev-Ner	2011		•	•		•			•	•	•	•		
Kristal	2011		•	•		•					•		•	
De Asha	2011		•	•		•	•		•					
Brown	2011		•	•		•			•					

Study Findings and Clinical Interpretation

Findings		Improved gait quality	Improved inter-limb symmetry	Reduced pressure/ loading rate	Improved balance/ stability/ clearance	Improved efficiency/joint mechanics	Improved user satisfaction
Potential benefit		**Increase mobility**	**Reduced risk of back pain, OA**	**Reduced risk of pressure ulcers**	**Reduced risk of falls**	**Less tiring to use**	**Better quality-of-life**
Quick reference							
Wurdeman	2019	•					
McGrath	2019	•	•	•	•	•	
Askew	2019	•				•	
Bai	2018	•	•		•		
Kannen-berg	2018	•	•	•	•	•	•
McGrath	2018		•		•		
McGrath	2018	•	•				
Abdulhasan	2018	•	•				
Moore	2018			•			
Barnett	2018	•	•				•
Alexander	2018					•	
Bai	2017	•	•				•
Dotan-Moram	2017		•				•
De Asha	2017	•				•	
Moore	2017	•					•
Struchkov	2016	•			•		
Moore	2016	•	•				
De Asha	2014	•				•	
Johnson	2014	•			•		
De Asha	2014	•					
Alexander	2014					•	
De Asha	2013	•	•			•	
Sedki	2012						•
De Asha	2012	•					
Kristal	2012	•		•			
Erler	2012	•	•		•	•	•
Portnoy	2012			•			•
De Asha	2012	•					
Siev-Ner	2011			•			
Kristal	2011		•		•		
De Asha	2011	•	•				
Brown	2011	•					

Full List of Studies

Full references found at the end of the compendium.

Mobility analysis of AmpuTees (MAAT 5): Impact of five common prosthetic ankle-foot categories for individuals with diabetic/dysvascular amputation

Authors: S.R. Wurdeman[1,2], P.M. Stevens[1,3], J.H. Campbell[1]

[1]Department of Clinical and Scientific Affairs, Hanger Clinic, Austin, TX, USA

[2]School of Allied Health Sciences, Baylor College of Medicine, Houston, TX, USA

[3]School of Medicine, University of Utah, Salt Lake City, UT, USA

Published in: Journal of Rehabilitation and Assistive Technologies Engineering 6, 2019

Summary

The functional mobility scores of 738 dysvascular patients, using five different prosthetic foot types, were retrospectively analysed and compared.

Method

Components: MPF: microprocessor ankle-foot, HA5968 – hydraulic ankle-foot system, VL5987 – shank-foot system with vertical loading pylon, FWS5981 – flex-walk system, FF5980 – flex-foot system

Measurements: T-score from functional mobility assessment (PLUS-M questionnaire)

Subjects: 738 (females in brackets) amputees, K3, diabetic/dysvascular patients

MPF: 28 (4) individuals, (14 unilateral trans-tibial (TT), 7 unilateral trans-femoral (TF), 7 bilateral (B)), 57.1±13 years, 98.7±16.8 kg

VL5987: 155 (11) individuals (121 TT, 16 TF, 18 B), 57.7±12.1 years, 101±23.9 kg

FWS5981: 342 (86) individuals (241 TT, 67 TF, 34 B), 58.8±10.4 years, 95.1±24.2 kg

FF5980: 123 (34) individuals (80 TT, 31 TF, 12 B), 58.6±11.8 years, 89.0±24.8 kg

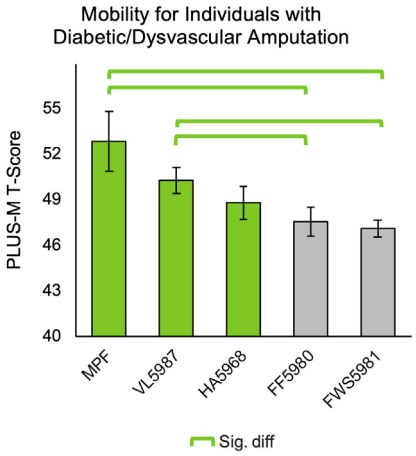
HA5968: 90 (15) individuals (66 TT, 7 TF, 17 B), 61.1±10.2 years, 90.5±18.2 kg

Data collection protocol: Patients were asked to complete the PLUS-M questionnaire during a routine standard of care appointment. These were then collected and sorted via inclusion criteria. The weighted values from the included questionnaires were summed and converted to a T-score which was then used for comparison.

Analysis: Patients were divided into groups dependent on what type of prosthetic device they were using. A general linear univariate model was used to compare groups and Fisher's least significant difference determined specific group differences.

Results

A significant difference in mobility was found across all groups (p=0.008). Individuals using MPF had the greatest mobility, although this was not significantly more than the vertical loading pylon (VL5987) condition, which had the second highest mobility score. There was no significant difference between the VL5987 condition and the third highest ranking hydraulic (HA5968) condition, however the flex-foot and flex-walk (FF5980, FWS5981) conditions both had significantly lower functional mobility scores than the top two conditions.



Conclusion

The authors suggest that, based on functional mobility provided, a top down approach should be utilised within a clinical setting when prescribing for vascular patients. Shank-foot with vertical loading pylon systems, such as the Elite2, resulted in a mobility score not dissimilar to that of a microprocessor-controlled foot, so should be considered, along with hydraulic ankle-foot systems like the Echelon, once a microprocessor option has been ruled out and ahead of other flex-foot and flex-walk options.

Products with Related Technology:

Elan, Echelon, EchelonVT, EchelonVAC, Elite2, EliteVT, Elite Blade, Elite BladeVT

Anforderungen an eine geeignete Prosthesentechnologie für ältere, dysvaskuläre Amputierte - Requirements of a suitable prosthesis technology for elderly, dysvascular amputees

Authors: M. McGrath[1], D. Moser[1], A. Baier[2]

[1]Blatchford Limited, Basingstoke UK

[2]Blatchford Deutschland, Kulmbach Germany

Published in: Orthopädie Technik 2019; 11: 42-46

Summary

An informative review was produced highlighting the most prevalent issues within the elderly amputee community. Evidence of the benefits gained from existing technologies (hydraulic ankles, elevated vacuum suspension and perforated liners) was collated and presented as a potential solution.

Method

Components: Hydraulic foot technology (namely Avalon)

Measurements: Review paper

Subjects: N/A

Data collection protocol: N/A

Analysis: A review of existing literature and technology in how to tackle current clinical challenges and user needs.

Results

Although there were many contributing factors, falling and soft tissue damage because of dysvascular issues were highlighted as the predominant risk factors within the elderly community of amputees. Prosthetic componentry was presented as an independent factor that would have a large effect on the risk of falling, with hydraulic ankles helping reduce the number of trips and falls by conforming to changeable terrain and increasing the minimum toe clearance during swing phase. The Avalon has been shown to reduce the amount of muscular effort during sit-to-stand by 33% and was seen to increase both ambulation and patient satisfaction. Elevated vacuum suspension was found to reduce movement at the residuum-socket interface, reducing tissue shear and increasing proprioception. The negative pressure produced by the vacuum improves tissue oxygenation in the residuum, and can promote wound healing, especially when combined with a perforated liner to aid with moisture wicking and temperature regulation.

Conclusion

Although falling and soft tissue damage pose challenges, prosthetic technology has proven methods of mitigating risk factors and, when using a combination of proven technologies, can not only improve short-term issues but also has beneficial implications long-term.

Products with Related Technology:

Avalon, Elan, Echelon, EchelonVAC

Energy cost of ambulation in trans-tibial amputees using a dynamic-response foot with hydraulic versus rigid 'ankle': insights from body centre-of-mass dynamics

Authors: G. Askew[1], L. A. McFarlane[1], A. E. Minetti[2], J. G. Buckley[3]

[1]School of Biomedical Sciences, Faculty of Biological Sciences, University of Leeds, UK

[2]Department of Pathophysiology and Transplantation, Faculty of Medicine, University of Milan, Italy

[3]Division of Biomedical Engineering, School of Engineering, University of Bradford, UK.

Published in: Journal of Neuroengineering and Rehabilitation 2019; 16:39

Summary

Trans-tibial amputees, walking at various speeds and over different gradients, displayed a greater energy efficiency when using a hydraulic ankle unit than when they were using a fixed ankle prosthesis.

Method

Components: Hydraulic ankle-feet (HyAnk – Echelon) and energy-storage-and-return feet (ESR – Esprit)

Measurements: O_2 uptake and CO_2 production, motion capture during treadmill walking

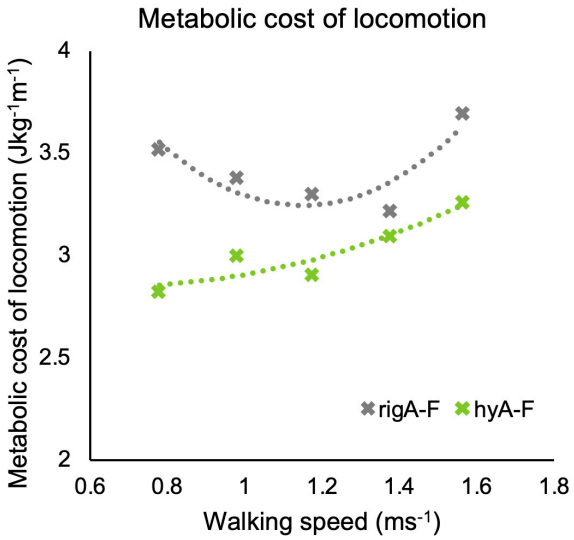
Subjects: Nine unilateral trans-tibial amputees (all male, mean±SD: age 41.3±14.3 years, mass 79.6±13.3kg, height 1.79±0.07m)

Data collection protocol: The participants walked on a level treadmill (at 0.8, 1.0, 1.2, 1.4, and 1.6 of customary walking speed) and on at two angles of decline (5° and 10°) for customary walking speed only. The participants repeated the protocol with an ESR and a HyAnk.

Analysis: 3D motion capture measured body segment kinematics, from which whole body centre-of-mass dynamics (BCOM), inter-limb symmetry and energy recovery potential could be derived. O_2 uptake was also used to quantify metabolic cost. Random intercepts modelling and chi-squared tests between models were also applied.

Results

The metabolic cost of locomotion was significantly reduced ($p<0.001$) by HyAnk compared to the ESR foot. Averaged across all level walking speeds, the metabolic cost of locomotion reduced was by 11.8±2.5% with HyAnk. Averaged across all gradients at the customary speed, the metabolic cost of locomotion reduced was by 20.2±3.4% with HyAnk. At metabolic costs of 14 ml kg^{-1} min^{-1} and 17 ml kg^{-1} min^{-1}, the mean customary walking speeds with the ESR foot were 1.09 and 1.37ms^{-1}, respectively. With HyAnk, these speeds increased by 6-7%, to 1.18 and 1.45ms^{-1}, respectively. HyAnk use also significantly reduced the total mechanical work done on a gradient and increased the interchange between the mechanical energies of the BCOM (recovery index), leading to a significant increase in locomotor efficiency ($p < 0.001$). Finally, it also increased inter-limb symmetry and reduced compensations.



Conclusion

The authors conclude that their findings suggest that hydraulic ankle use should provide meaningful benefits to the user's everyday walking by improving energy efficiency. They state that this will be particularly beneficial to those who can walk at different speeds and over different gradients.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

A biomechanical assessment of hydraulic ankle-foot devices with and without microprocessor control during slope ambulation in trans-femoral amputees

Authors: X. Bai[1], D. Ewins[1,2], A.D. Crocombe[1], W. Xu[1]

[1]Department of Mechanical Engineering Sciences, University of Surrey, Guildford, UK

[2]Gait Laboratory, Queen Mary's Hospital, Roehampton, London, UK

Published in: PLoS ONE 2018; 13(10): e0205093.

Summary

The biomechanical effects of a rigidly-attached foot, a passive hydraulic ankle and a microprocessor-controlled hydraulic ankle were measured during slope ascent and descent for trans-femoral amputees. The hydraulic ankles showed improved bio-mimicry in both walking conditions and better prosthetic knee stability during slope descent.

Method

Components: Esprit, Echelon, Elan

Measurements: 3D gait analysis on a 5° slope

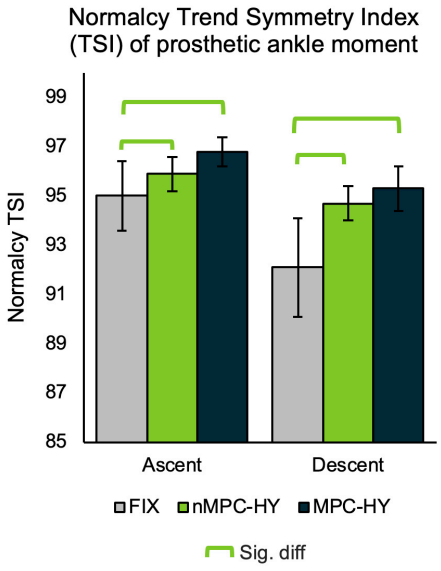
Subjects: Five active unilateral, trans-femoral amputees, K3/4 (all male, 42±17years, 107±16kg, 1.83±0.02m) and 14 non-amputee subjects (5 male, 9 female, 26±2 years, 68±15kg)

Data collection protocol: Each of the amputees used a fixed ankle, a passive hydraulic ankle or a microprocessor-controlled hydraulic ankle with their habitual prosthetic knee. 3D gait analysis recorded kinematic and kinetic data as the subjects walked up and down a 5° slope. The control subjects also performed these tests. The amputees were also asked to complete a feedback questionnaire.

Analysis: Trend Symmetry Indices (TSI) were calculated for symmetry between prosthetic and sound limbs and for 'normalcy' (compared to control subjects). Shapiro-Wilk tests were used to assess data normality and repeated measures one-way ANOVA tests were performed for walking condition and for prosthetic foot. Post-hoc analyses were conducted with post-hoc Tukey tests.

Results

The mean walking speeds were not significantly different across prosthetic conditions. The hydraulic ankles presented an increased range of motion, compared to the rigidly-attached foot, as well as improved bio-mimicry of the prosthetic ankle moment, indicated by the normalcy TSI. In addition, the hydraulic ankles increased mid-stance external prosthetic knee extensor moment during downhill walking. Compared to the passive hydraulic ankle, the microprocessor hydraulic ankle further improved these parameters, significantly increasing mid-stance external prosthetic knee extensor moment during downhill walking (p=0.027). Subjects thought that the hydraulic ankle offered improvements over the fixed ankle, specifically highlighting the improved safety offered when descending slopes.



Conclusion

The authors conclude that the major benefits of hydraulic ankles, compared to rigidly-attached feet, are slope adaptation during gradient walking and increased safety during slope descent. The improved range of motion and normalcy TSI values indicate better adaptation to the slope. The increase in prosthetic knee extensor moment during mid-stance is interpreted as improved knee stability, allowing a safer descent. The microprocessor hydraulic ankle further improved knee stability in slope descent compared to the passive hydraulic ankle.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Evidence on prosthetic feet with active dorsiflexion feature, passive microprocessor control and active ankle power generation: a mini literature review

Authors: A. Kannenberg[1]

[1]Department of Medical Affairs, Otto Bock HealthCare, Austin, TX, USA.

Published in: Canadian Prosthetics and Orthotics Journal 2018; 1(1) No.6.

Summary

A literature review was undertaken of the published scientific evidence for passive prosthetic feet with active dorsiflexion features (including hydraulic ankles), microprocessor feet and actively-powered prosthetic feet. Each advance in technology was reported to produce extra patient benefits.

Method

Components: Prosthetic feet with active dorsiflexion (hydraulic ankles), microprocessor feet, actively powered feet

Measurements: Review paper

Subjects: N/A

Data collection protocol: N/A

Analysis: A review of previous scientific literature.

Results

Non-microprocessor feet with the active dorsiflexion feature were reported to increase prosthetic toe clearance during walking, compared to feet without this feature, leading to a reduced risk of tripping. A reduction in braking force during level walking was thought to contribute to the increased walking speed, generally reported with this type of prosthetic foot. Microprocessor feet that retain the active dorsiflexion feature will also retain the benefit of reduced likelihood of tripping. They may also reduce energy expenditure during level walking and help with slope and stair negotiation. Both non-microprocessor and microprocessor feet that have damped ankle movement will reduce pressures at the interface between residual limb and socket. Actively powered feet increase walking speed and further improve energy efficiency.

Conclusion

The author concludes that prosthetic feet with damped ankles, both with and without microprocessor-control, will be well suited to amputees with reduced toe clearance, or a tendency to trip. They could also be considered for those who experience increased residual limb stress while negotiating uneven terrain, slopes and/or stairs.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Microprocessor knees with "standing support" and articulating, hydraulic ankles improve balance control and inter-limb loading during quiet standing

Authors: M. McGrath[1], P. Laszczak[1], S. Zahedi[1], D. Moser[1]

[1]Endolite Technology Centre, Basingstoke UK

Published in: Journal of Rehabilitation and Assistive Technologies Engineering (RATE). 2018; 5:2055668318795396. Smart Limb Technology Special Issue

Summary

The biomechanical differences were measured when trans-femoral amputees use rigidly-attached ankles or hydraulic ankles, while standing on a slope. The activation of MPK-enhanced standing mode was varied between on and off. Both advanced technologies brought about improvements in weight distribution and balance, while the combination of hydraulic ankle and MPK standing mode was determined to provide the best performance.

Method

Components: Echelon VT, Esprit, Orion3 microprocessor knee

Measurements: Kinematics and kinetics during static standing

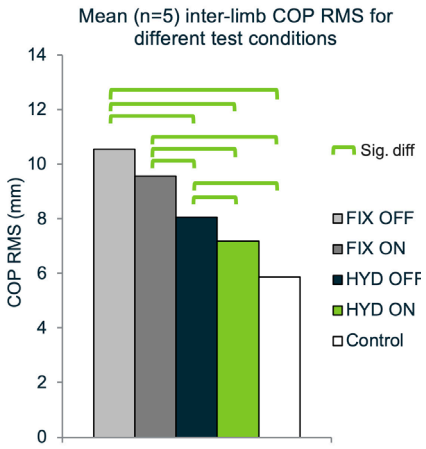
Subjects: Five trans-femoral amputees (4 male, 1 female; 41.6±12.8 years; 77.2±20.0kg) and five able-bodied controls (27.4±2.9 years; 66.8±10.3kg)

Data collection protocol: Each amputee was asked to stand still, facing down a 5° decline, for a period of 14 seconds at a time, while their joint angles, ground reaction force (GRF) and centre-of-pressure (COP) were monitored. This was repeated multiple times. The protocol was repeated using a rigidly-attached foot and a hydraulic ankle-foot unit, in a randomised sequence with a 30 minute acclimatisation period between each condition.

Analysis: Degree of asymmetry (DOA) was used to compare inter-limb symmetry. Centre-of-pressure root mean square (COP RMS) was used as a measure of balance. Paired t-tests and non-parametric Wilcoxon tests were used to identify significant differences.

Results

In terms of kinematics, the differences between the two foot types were noticeable. The rigidly attached foot required increased hip and knee flexion on the prosthetic side in order to achieve 'foot-flat', while the hydraulic ankle complied with the slope, allowing a more upright posture. With the MPK standing mode off, the effect of foot type on the GRF distribution was pronounced. Four of the five amputees displayed increased normal GRF on the prosthetic side (7-24%, $p<0.001$) when using the hydraulic ankle, while all five showed increased prosthetic shear GRF (14-99%, $p<0.01$). On the sound side, normal GRF reduced for three (4-20%, $p<0.001$) and shear GRF reduced for four (14-53%, $p<0.001$) when compared to the rigid ankle. For all amputees, DOA of normal GRF was improved when using the hydraulic, indicating a more even inter-limb load distribution. COP RMS was significantly reduced for three amputees when using a hydraulic ankle compared to a rigidly-attached foot, with MPK standing mode off, and was significantly reduced for all five with standing mode on, implying increased balance of the user. The cohort mean inter-limb COP RMS was calculated for each prosthetic condition and the controls. The effect of hydraulic ankle on balance was greater (24-25%) than that of standing mode (9-11%). The combination of the two technologies produced the result closest to that of the able-bodied control participants.



Conclusion

Less kinematic compensation was required to achieve foot-flat on the non-level surface when using the hydraulic ankle, due to its ability to self-align and adapt better to gradient than the rigid ankle. This decreases the loading of the sound limb joints and improves balance.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

The influence of a microprocessor controlled hydraulic ankle on the kinetic symmetry of trans-tibial amputees during ramp walking: A case series

Authors: M. McGrath[1], P. Laszczak[1], S. Zahedi[1], D. Moser[1]

[1]Endolite Technology Centre, Basingstoke UK

Published in: Journal of Rehabilitation and Assistive Technologies Engineering (RATE). 2018; 5:2055668318790650. Smart Limb Technology Special Issue

Summary

The microprocessor-control of an Elan hydraulic ankle was switched on and off for amputees walking up and down a 5° slope. Gait analysis was performed to identify differences in the underlying walking biomechanics between the on and off conditions.

Method

Components: Elan

Measurements: 3D gait analysis

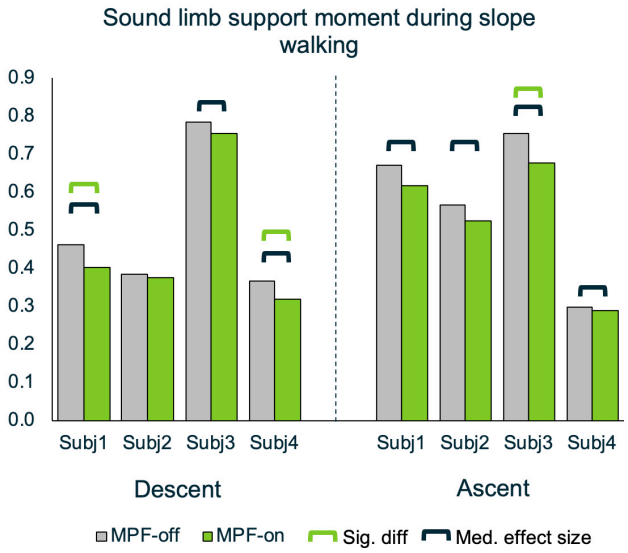
Subjects: Four trans-tibial amputees, K3 (all male; 36.8±10.6 years; 76.5±14.2kg)

Data collection protocol: 3D gait analysis was performed for two conditions (walking up and down a 5° slope) and for two prosthetic foot settings (MPF-on and MPF-off). The order of these tests was randomised and participants were given a 30 minute acclimatisation period between each trial.

Analysis: The main outcome measure was the integral of the 'support' moment curve for each limb (MI_{sup}). Degree of asymmetry (DOA) was used to compare inter-limb symmetry. Shapiro-Wilk tests were used to assess data normality, before either paired t-tests or non-parametric Wilcoxon tests identified significant differences between foot conditions. The effect size was also evaluated using Cohen's d (where d ≥0.4 was deemed a 'medium' effect size).

Results

During slope descent, the largest changes in moment integral were at the prosthetic 'ankle' for all amputees. The transition from dorsiflexion to plantarflexion moment occurred at approximately 10–20% of stance with the MPF-on, compared to approximately 20–26% of stance with the MPF-off, implying less resistance to plantarflexion and more resistance to dorsiflexion movement. Three of the four showed significant increases in prosthetic MI_{sup} (all four d ≥0.4), and two showed significant decreases in sound MI_{sup} (three of four d ≥0.4). Three had a DOA closer to 0 (i.e. improved symmetry) while the fourth showed greater reliance on the prosthetic side, than the sound side. During slope ascent, two showed significant increases in prosthetic MI_{sup}. All four showed a reduction in sound MI_{sup} (d ≥0.4).



Conclusion

The authors equate the moment-time integrals at the prosthetic 'ankle' to the MPF altering the hydraulic resistances, illustrating the 'braking' effect during descent and the 'assistance' effect during ascent. This had the effect of reducing the reliance on the sound limb during both slope descent and ascent.

Products with Related Technology:

Linx, Elan

Gait termination on a declined surface in trans-femoral amputees: Impact of using microprocessor-controlled limb system

Authors: Z. M. Abdulhasan[1], A. J. Scally[2], J. G. Buckley[1]

[1]Division of Biomedical Engineering, School of Engineering, University of Bradford, UK

[2]School of Health Studies, University of Bradford, UK

Published in: Clinical Biomechanics 2018; 57: 35-41

Summary

Eight trans-femoral amputees, using an integrated limb system, performed gait terminations while walking downhill. Two prosthetic conditions were tested; microprocessor-control active and inactive. Greater involvement of the prosthetic limb with the microprocessor active indicated greater confidence in their prosthesis and reduced reliance on the healthy limb.

Method

Components: Linx (microprocessor-control active and inactive)

Measurements: 3D gait analysis

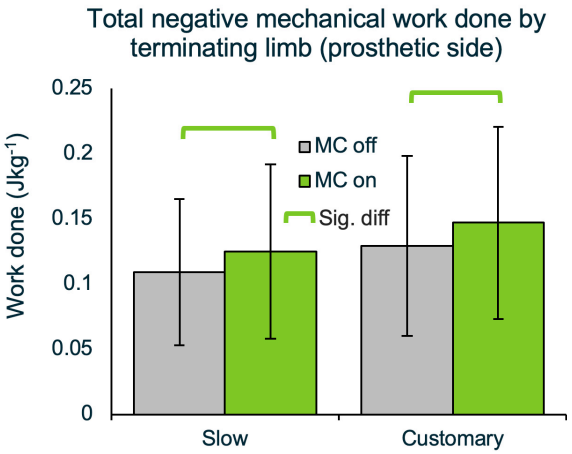
Subjects: Eight unilateral trans-femoral amputees, K3 (all male; 47.6±13.3years; 87.1±17.1kg; 1.78±0.08m)

Data collection protocol: Participants wore an integrated limb (Linx) consisting of a microprocessor knee and microprocessor hydraulic ankle-foot, which communicate with one another via a single master controller. They completed repeated gait analysis trials walking along a 4m, 5° declined walkway at slow and customary walking speeds. They were asked to perform gait terminations on the prosthetic limb, specifically. The trials were performed with Linx's microprocessor-control active (MCon) where the limb automatically adjusted during gait, and inactive (MCoff), where hydraulic resistances provided by the knee and ankle reverted to default settings for the user.

Analysis: Data were analysed using a random-effects regression model with maximum likelihood estimator. Factors and interaction between these factors tested were: (1) Walking speed: two levels, slow and customary (2) Microprocessor condition: two levels, inactive (MCoff), active (MCon).

Results

The time taken to stop was significantly shorter with the MCon condition (p=0.021). Negative mechanical limb work done in the prosthetic limb was significantly increased for the MCon condition (p=0.004), by an average of 14% and 16%, for slow and customary walking speeds, respectively.



Conclusion

The authors conclude that the increased negative work indicates a greater involvement of the prosthetic limb. Their findings also suggest that using an integrated limb improves walking and stopping on ramps. They hypothesise that use of such a prosthesis should provide clinically meaningful benefits for trans-femoral amputees in their everyday life, which may involve changing walking surfaces and giving them greater confidence in their prosthesis.

Products with Related Technology:

Linx, Elan

Effect of a prosthetic foot with a hydraulic ankle unit on the contralateral foot peak plantar pressures in individuals with unilateral amputation

Authors: R. Moore[1]

[1]Luton and Dunstable Hospital Trust, Luton, Bedfordshire, UK

Published in: Journal of Prosthetics and Orthotics (JPO) 2018; 30(3): 165-70.

Summary

Plantar pressure under the sound foot was measured for thirteen unilateral amputees, using prosthetic feet with and without hydraulic ankle units. There was a significant reduction in plantar pressure when using the hydraulic ankle.

Method

Components: Echelon, previous non-hydraulic ankle-foot

Measurements: Contralateral foot plantar pressure

Subjects: Thirteen unilateral K3 amputees (12 male, 1 female; 8 trans-tibial, 5 trans-femoral)

Data collection protocol: Participants walked over an Amcube pressure platform with their contralateral foot, back and forth along a 6m walkway, with their originally prescribed prosthetic foot. Each walked for a total of five minutes in order to record a sufficient number of steps. They were then fitted with an Echelon hydraulic ankle and acclimatised to the device for a period of four weeks. Subsequently, they returned to the clinic and repeated the plantar pressure measurement test, this time using the hydraulic ankle.

Analysis: Paired t-tests comparing peak pressures with and without the hydraulic ankle units.

Results

All 13 patients showed a decrease in contralateral foot peak plantar pressures when using the prosthetic foot with the hydraulic ankle unit. The mean reduction was 48kPa (p=0.002). The two largest reductions were both trans-femoral patients (165kPa and 129kPa reductions, respectively).

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	Mean
Pre-Echelon (kPa)	132	221	192	185	331	200	105	131	162	176	186	274	150	188
Echelon (kPa)	92	134	162	156	166	199	90	84	138	149	158	145	143	140
Difference	-40	-87	-30	-29	-165	-1	-15	-47	-24	-27	-28	-129	-7	**-48**

Conclusion

The authors conclude that maintaining the contralateral limb should be viewed as an issue of great priority. The inclusion of a hydraulic ankle on the prosthetic side can directly play a statistically significant part in the health and longevity of the sound limb. With respect to the two large reductions for the trans-femoral patients, the authors state that because these reductions were observed at the forefoot and metatarsal heads, it is likely that Echelon reduced the necessity to hip-hike, due to its greater toe clearance.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC

Individuals with unilateral trans-tibial amputation and lower activity levels walk more quickly when using a hydraulically articulating versus rigidly-attached prosthetic ankle-foot device: A case series

Authors: C. Barnett[1], O. Brown[1], M. Bisele[1], M. Brown[2], A. De Asha[3], G. Strutzenberger[4]

[1]School of Science and Technology, Nottingham Trent University, Nottingham, UK.

[2]HAS Motion Inc., 27 Sydenham Street, Kingston, ON, Canada.

[3]C-Motion, Inc., 20030 Century Blvd. Suite 104A, Germantown, MD, USA.

[4]Department of Sport Science and Kinesiology, University of Salzburg, Austria.

Published in: Journal of Prosthetics and Orthotics (JPO) 2018; 30(3): 158-64.

Summary

Two minute walk tests and 3D gait analysis were performed on lower mobility amputees, using both a rigidly-attached ankle-foot and an articulating, hydraulic ankle-foot. The hydraulic device was shown to increase walking speed and inter-limb loading symmetry.

Method

Components: Avalon, Navigator

Measurements: 3D gait analysis, two minute walk test (2MWT), Activities-Specific Balance Confidence (ABC) scale, Houghton scale, Prosthetic Limb Users Survey of Mobility (Plus-M)

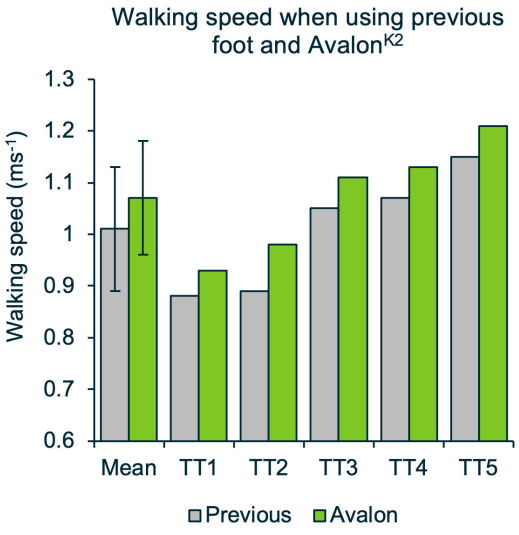
Subjects: Five K2 unilateral, trans-tibial amputees (4 male, 1 female; 53.4±4.5years; 86.7±12.1kg)

Data collection protocol: 3D gait analysis recorded kinematic and kinetic data during 2MWTs and ten over-ground gait trials. This protocol was repeated with a rigidly-attached ankle-foot device (RIG) and using a hydraulically articulating ankle-foot device (HYD).

Analysis: Case series analysis, differences were quantified using a Cohen's clinical effect size analysis, with d=0.4, or a 'medium effect size', being defined as clinically meaningful.

Results

Walking speed was increased by 6.5% on average, in the HYD (Avalon) condition, compared to the RIG (Navigator) condition (d = 0.4). Participants displayed more symmetrical inter-limb loading (d = 0.8), increased minimum forward centre-of-pressure velocity (d = 0.8) and increased peak shank rotational velocity (d = 1.0) when using the HYD compared to RIG device, however prosthetic energy efficiency was decreased (d = 0.7).



Conclusion

The authors conclude that hydraulic ankles improved mobility and walking ability in the K2 population, as they were able to walk faster and hence further during the 2MWT. The hydraulic articulation of the ankle in early stance phase reduced the stance braking effect, which partially contributed to the measured increase in walking speed.

Products with Related Technology:

Avalon

Joint moments during downhill and uphill walking of a person with trans-femoral amputation with a hydraulic articulating and a rigid prosthetic ankle - a case study

Authors: N. Alexander[1], G. Strutzenberger[1], J. Kröll[1], C.Barnett[2], H. Schwameder[1]

[1]Department of Sport Science and Kinesiology, University of Salzburg, Austria

[2]School of Science and Technology, Nottingham Trent University, Nottingham, UK.

Published in: Journal of Prosthetics and Orthotics (JPO) 2018; 30(1): 46-54.

Summary

This gait analysis study sought to investigate the effects of a microprocessor-controlled hydraulic ankle compared to a fixed ankle design when walking at a range of graded inclines, ranging from -12 to +12 degrees.

Method

Components: Dynamic response style foot (Esprit, "RIGID") and a microprocessor-controlled, articulating hydraulic ankle (Elan "ARTIC"). The subject used a microprocessor-controlled knee (Orion) throughout.

Measurements: 3D gait analysis with 12 cameras (Vicon) and ground reaction forces from two force plates (AMTI) built into a hydraulically adjustable ramp walkway.

Subjects: A single unilateral trans-femoral amputee (male; 44 years; 85kg; 1.84m; traumatic aetiology; 29 years previous). Able-bodied control group (n=18; all male; 27±5years; 75±8kg; 1.80±0.05m).

Data collection protocol: Randomised crossover testing of each foot. The subject walked at a self-selected speed on a ramp at five different gradients: -12°, -4°, 0°, 4° and 12°. He performed five trials on each gradient, for each prosthetic condition. No data existed at 4º gradient for the able-bodied group so between-group comparisons were limited to level-ground walking and gradients at ±12º.

Analysis: Measurements were time-normalised over stance phase and normalised to body mass. The mean value was calculated for each outcome measure over the five trials.

Results

The changes in gradient effected joint kinetics similarly in the amputee participant and the able-bodied control group. The prosthetic ankle-foot condition had the greatest influence at the residual hip. Compared to the "RIGID" condition, the "ARTIC" reduced the mean hip extension and flexion moments by up to 92% and 48%, respectively, depending upon slope gradient. Peak vertical GRF values at terminal stance were similar to that of the able-bodied group on a downhill slope when using the ARTIC and an increased walking speed was observed during level walking when compared to the RIGID condition.

Conclusion

The Authors conclude that the effect of the microprocessor-controlled hydraulic ankle was to improve gradient walking for the amputee participant. The reduction in residual hip moment implies a benefit, which may result in a more efficient gait and decreased energy consumption as a consequence.

Products with Related Technology:

Linx, Elan

Kinematic and biomimetic assessment of a hydraulic ankle-foot in level ground and camber walking

Authors: X. Bai[1], D. Ewins[1,2], A.D. Crocombe[1], W. Xu[1]

[1]Department of Mechanical Engineering Sciences, University of Surrey, Guildford, UK

[2]Gait Laboratory, Queen Mary's Hospital, Roehampton, London, UK

Published in: PLoS ONE 2017; 12(7): e0180836

Summary

The biomechanical effects of a hydraulic ankle, compared to a rigidly-attached foot, were measured during level walking at normal and fast speed and during cambered walking. The hydraulic ankle showed improved inter-limb symmetry and produced joint moments closer to those of able-bodied control subjects.

Method

Components: Echelon, Esprit

Measurements: 3D gait analysis on a level walkway and a 2.5° cambered walkway and a feedback questionnaire.

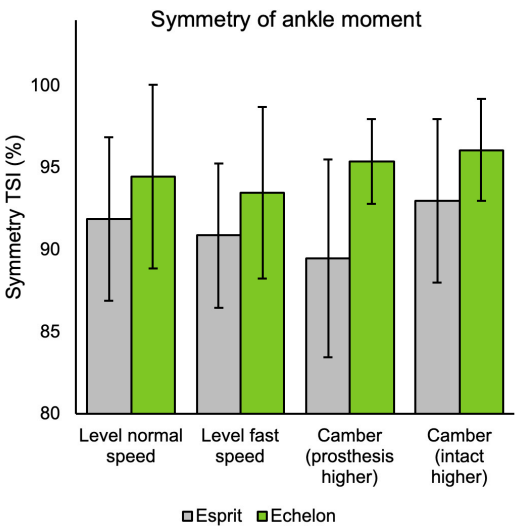
Subjects: Five active unilateral, trans-femoral amputees (42.4±15.7years, 107.4±12.1kg) and 12 non-amputee subjects (5 male, 7 female; 26±2 years; 68±15kg)

Data collection protocol: Each of the amputees used a fixed ankle or a passive hydraulic ankle with their habitual prosthetic knee. 3D gait analysis recorded kinematic and kinetic data as the subjects walked at normal and fast speeds on a level surface. They also walked on a surface with a 2.5° camber. Trials were recorded with the prosthetic foot higher up the slope and with the sound foot higher up the slope. The control subjects also performed these tests. The amputees were also asked to complete a feedback questionnaire.

Analysis: Trend Symmetry Indices (TSI) were calculated for symmetry between prosthetic and sound limbs and for 'normalcy' (compared to control subjects). Repeated measures two-way ANOVA tests were performed for walking condition and for prosthetic foot. Post-hoc analyses were conducted with post-hoc Tukey tests.

Results

The amputees walked with significantly longer strides when using the Echelon ($p=0.026$) and at faster walking speeds, although this parameter was not statistically significant. Significant differences were found between the prosthetic ankle moments of the hydraulic and fixed devices, in both symmetry and normalcy TSI ($p<0.001$ in two TSI parameters), where the Echelon foot showed higher TSI values than the Esprit foot. This held true for all four walking conditions. The questionnaire feedback indicated that the hydraulic ankle felt more stable, made swing phase easier, provided a more balanced feeling, was less limiting to movement and provided an overall safer feeling. This was the case for all walking conditions.



Conclusion

The authors conclude that the improved ankle moment symmetry and bio-fidelity indicate a major advantage for hydraulic ankle users. These advantages can be measured consistently, across different walking speeds and non-level ground, which relates to real world scenarios. The increased stride length achieved with the hydraulic ankle indicates improved performance while the questionnaire shows a user preference for the hydraulic device.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Gait characteristics in trans-tibial amputees ambulating with and without a microprocessor-controlled hydraulic prosthetic ankle

Authors: Y. Dotan-Moram[1,2], S. Portnoy[3,4], A. Kristal[1], H. Sharon [2], I. Siev-Ner[1,2]

[1]Department of Orthopedic Rehabilitation, Sheba Medical Centre, Tel Hashomer, Israel

[2]Centre of Advanced Technologies in Rehabilitation, Sheba Medical Centre, Tel Hashomer, Israel

[3]Department of Occupational Therapy, Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

[4]Department of Physical Medicine and Rehabilitation, Hadassah Medical Centre, Jerusalem, Israel

Presented at: International Society for Prosthetics and Orthotics (ISPO) World Congress. 8-11th May 2017, Cape Town, South Africa

Summary

The difference between microprocessor-controlled and non-microprocessor-controlled hydraulic ankle-foot devices were assessed using an instrumented treadmill. Biomechanical parameters and subjective feedback were used as outcome measures.

Method

Components: Elan, Echelon

Measurements: Plantar pressure, centre-of-pressure (COP) trajectory, Prosthesis Evaluation Questionnaire (PEQ) – a patient reported outcome measure instrument

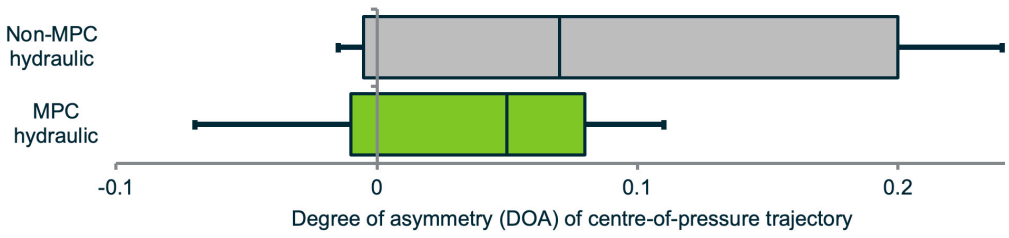
Subjects: Twelve, unilateral, trans-tibial amputees (60.4±9.9 years; 81.0±9.5 kg)

Data collection protocol: Each participant walked for three minutes on an instrumented treadmill in four conditions. These were level at self-selected and fast velocities, inclined 5° and declined 5°. The amputees' satisfaction and perception of their own mobility were evaluated with the PEQ. The protocol was first performed with the amputees' habitual Echelon ankle-foot devices. Next, each was provided with an Elan and given four weeks to acclimatise to the device, after which the protocol was repeated.

Analysis: Degree of asymmetry (DOA) was used to compare the anteroposterior movement of the COP under the prosthetic and sound feet. Wilcoxon signed-rank tests identified significant differences between DOA, peak plantar pressure, COP trajectory and PEQ responses.

Results

Using the Elan, the DOA of the COP trajectory between prosthetic and sound limbs decreased significantly for the level (self-selected velocity) and inclined walking tests. Significant increases in the plantar pressure under the prosthetic heel were reported when using Elan for fast and inclined walking. The mean PEQ score increased significantly with Elan (88.5; p=0.001) compared to Echelon (75.5). Scores improved by 20.6 and 28.1 when participants were asked to rate their own ability to walk up and down steep hills, respectively.



Conclusion

The authors stated that the decreased DOA of the COP trajectory when using Elan suggests a more efficient weight transfer over the ankle. The greater force under the heel during fast or inclined walking relates to the 'assist' function the microprocessor-control provides. For these conditions, plantarflexion resistance is high, in order to provide greater energy return from the heel spring.

Products with Related Technology:

Linx, Elan

Which Prosthetic Foot to Prescribe?: Biomechanical Differences Found during a Single-Session Comparison of Different Foot Types Hold True 1 Year Later

Authors: A. De Asha[1], C. Barnett[2], V. Struchkov[3], J. Buckley[3]

[1]C-Motion Inc, Germantown, Maryland, UK

[2]School of Science and Technology, Nottingham Trent University, UK

[3]Division of Medical Engineering, School of Engineering, University of Bradford, UK

Published in: Journal of Prosthetics and Orthotics (JPO) 2017; 29(1): 39-43.

Summary

A case study was performed in which gait analysis was used to assess the gait of a unilateral trans-tibial amputee using Epirus and Elan feet. The process was repeated 14 months later and the same differences were observed between the two feet types.

Method

Components: Epirus, Elan

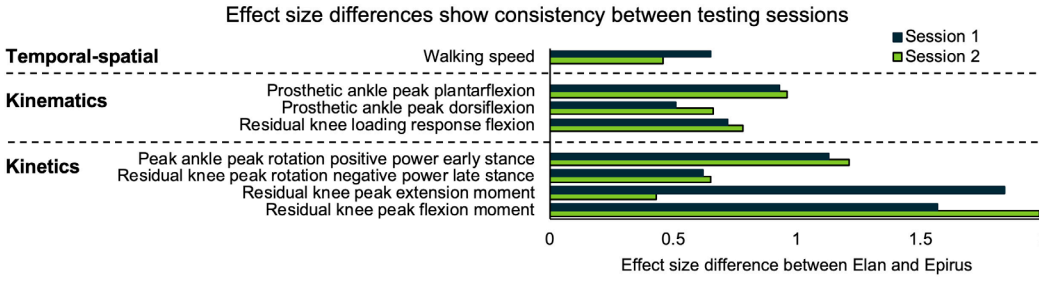
Measurements: 3D gait analysis

Subjects: A single K4 unilateral trans-tibial amputee (35.8 years; 90.4kg (1st session); 96.4kg (2nd session))

Data collection protocol: 3D motion was captured as the amputee completed 12 walking trials, at a self-selected speed, over an 8m walkway with two integrated force plates. This was performed for both prosthetic feet. The amputee's habitual foot was an Echelon VT so acclimatisation to each foot didn't bias results. A second session was conducted 14 months later where the protocol, trial order, laboratory setup, experimenters and prosthetist were identical. The same method was employed to align the devices.

Analysis: Various gait parameters were compared and clinically meaningful differences were defined as those with an effect size difference (d) between prosthetic conditions of at least 0.4 (medium effect size). No inferential statistical tests were applied.

Results



Clinically meaningful differences between feet were observed for eight gait parameters during the first session and again during the second session. These parameters were walking speed, peak plantarflexion and dorsiflexion at the prosthetic ankle, residual knee loading response flexion, peak positive power during early stance at the prosthetic ankle, peak negative residual knee power during late stance, and peak stance phase extension and flexion moments at the residual knee. The mean effect size difference between foot types was similar over both sessions for each parameter, respectively.

Conclusion

The authors conclude that given the comparable differences between foot type at both sessions, even with a change in patient condition, that a single-session comparison, as conducted within a clinical setting, is sufficient for identifying biomechanical gait differences between two devices. With respect to the performance of the different feet, the higher self-selected walking speed with Elan (1.39±0.08m/s and 1.38±0.09m/s for sessions 1 & 2, respectively), compared with Epirus (1.31±0.10m/s and 1.33±0.07m/s for sessions 1 & 2, respectively) can be considered a global descriptor of improved gait function. They also interpret the reduction in peak negative residual knee power in late stance when using Elan (1.51±0.30m/s and 1.89±0.37m/s for sessions 1 & 2, respectively), compared to Epirus (1.76±0.25m/s and 2.15±0.17m/s for sessions 1 & 2, respectively), as a beneficial change.

Products with Related Technology:

Linx, Elan

Patient Evaluation of a Novel Prosthetic Foot with Hydraulic Ankle Aimed at Persons with Amputation with Lower Activity Levels

Authors: R. Moore[1]

[1]Luton and Dunstable Hospital NHS Foundation Trust, Luton UK

Published in: Journal of Prosthetics and Orthotics (JPO) 2017; 29(1): 44-47.

Summary

A group of limited community walkers were asked to evaluate their existing prosthesis before starting a trial of an Avalon hydraulic ankle-foot device. After a four week period, they evaluated the Avalon.

Method

Components: Multiflex, Avalon

Measurements: Prosthesis Evaluation Questionnaire (PEQ) – a patient reported outcome measure instrument

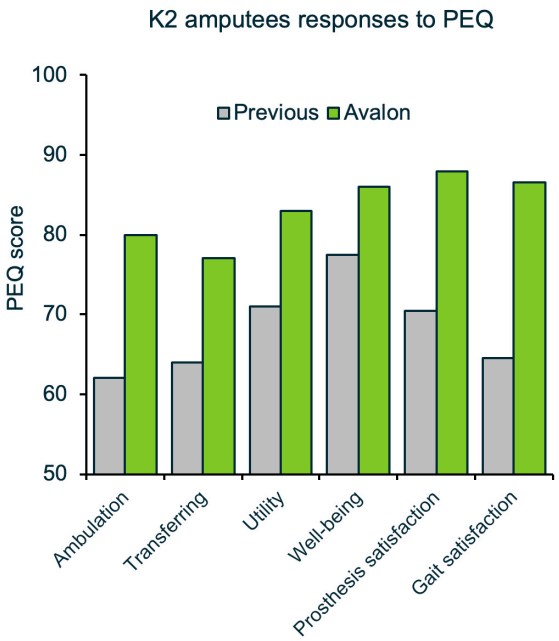
Subjects: Fourteen K2 patients (12 male, 2 female; 11 unilateral trans-tibial, 1 bilateral trans-tibial, 2 unilateral trans-femoral; 38-84 years).

Data collection protocol: Patients were asked to complete the PEQ in relation to their Multiflex feet. They were then supplied with an Avalon hydraulic ankle-foot device, which they wore for an acclimatisation period of four weeks. At the end of the trial, they were asked to complete the PEQ again, this time with respect to the Avalon foot.

Analysis: Scores from the questionnaire were separated by amputation level and broken down into categories of question (ambulation, transferring, utility, well-being, prosthesis satisfaction, gait satisfaction). Results from the two evaluations were compared between amputation levels and as a whole.

Results

When considering the subject group as a whole, the mean scores in each of the six question categories was consistently higher for the Avalon. The mean improvement across all categories was 14.7 points. This included a 17.3 point improvement in ambulation, a 17.2 point improvement in prosthesis satisfaction and a 21.9 point increase in gait satisfaction. When broken down by amputation level, trans-tibial amputees had a mean improvement across all categories of 16.6 points. For trans-femoral amputees the cross-category mean improvement was 6.2.



Conclusion

The author concludes that the statistically significant improvements in gait and overall prosthesis satisfaction when using the Avalon highlight the device's efficacy. He suggests further gait analysis could be performed to identify the causes of these perceived improvements.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Biomechanics of ramp descent in unilateral trans-tibial amputees: Comparison of a microprocessor-controlled foot with conventional ankle–foot mechanisms

Authors: V. Struchkov[1], J.G. Buckley[1]

[1]Division of Medical Engineering, School of Engineering, University of Bradford, UK

Published in: Clinical Biomechanics 2016; 32: 164-170.

Summary

A microprocessor-controlled ankle-foot device was compared to the more conventional mechanical device, in terms of its effect on gait parameters during ramp descent.

Method

Components: Elan, Epirus

Measurements: 3D gait analysis, temporal-spatial parameters

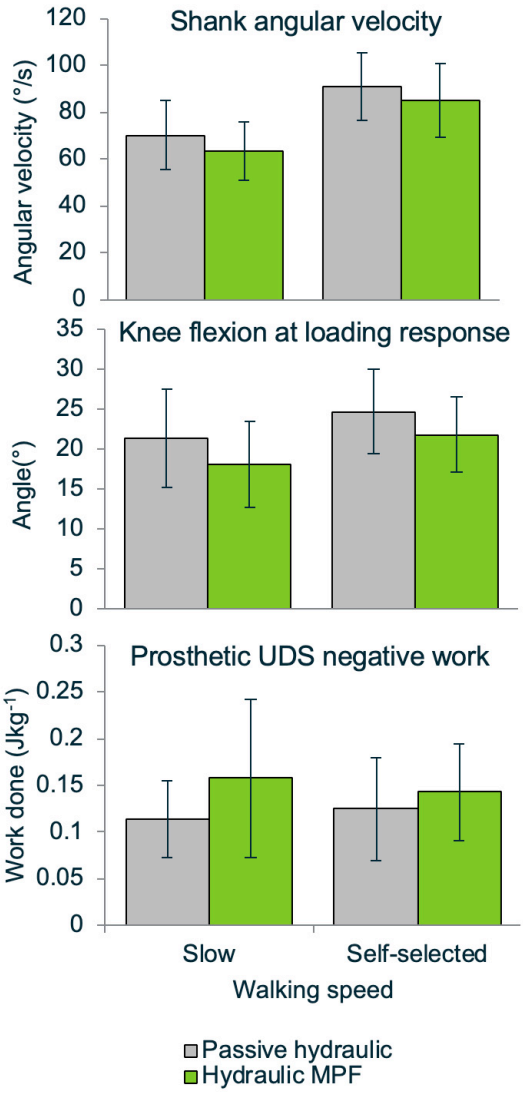
Subjects: Nine K3, unilateral, trans-tibial amputees (41.2±12.9 years; 74.14±15.7 kg)

Data collection protocol: Subjects repeatedly walked down a 5° ramp while gait analysis was performed for a slow walking speed and a self-selected speed. They would either have a rigid attachment ankle ('elastic'), a hydraulic ankle with settings optimised for level walking ('non-MPC') or a hydraulic ankle with intelligence to adapt to slope walking ('MPC').

Analysis: Residual limb kinematics, joints moments/powers and prosthetic foot power absorption/return were averaged across trials for each subject and normalised to body-weight. Kolmogorov-Smirnov tests indicated normal distributions and a repeated measures ANOVA was used to compare across ankle types and speed categories. To assess the effects of habitual use of prosthesis in some subjects, analyses were repeated using a mixed-design ANOVA with the patient's habitual foot as a 'between factor', Significant results were analysed using post-hoc Tukey HSD tests.

Results

Foot-flat occurred earliest with the rigid ankle foot and second earliest with the MPC ($p<0.001$); it occurred later at the slower speed across both foot types ($p<0.001$). Prosthetic shank single-support mean rotation velocity ($p=0.006$) and residual knee flexion ($p<0.001$) were reduced by walking speed and use of the MPC. Negative work done was decreased at the residual knee ($p=0.08$) and increased in the prosthetic side ankle-foot ($p<0.001$) when using the MPC, irrespective of speed. This suggests a reduction in sound side compensation.



Conclusion

The authors conclude that using MPC hydraulic feet will reduce the biomechanical compensations used to walk down slopes. Unilateral trans-tibial amputees often report difficulty with descending slopes more slowly – the increased negative prosthetic ankle work during stance phase illustrates the increased resistance to dorsiflexion, or 'braking effect' provided by the MPC. The reduced prosthetic shank rotation velocity in single support when using the active hydraulic ankle suggests that this technology helps to control descent speed, improving the safety of the user.

Products with Related Technology:

Linx, Elan

Effect on stance phase timing asymmetry in individuals with amputation using hydraulic ankle units

Authors: R. Moore[1]

[1]Luton and Dunstable Hospital NHS Foundation Trust, Luton UK

Published in: Journal of Prosthetics and Orthotics (JPO) 2016; 28(1): 44-48.

Summary

The gait kinematics of a number of lower limb amputees were measured with their conventional feet (i.e. non-hydraulic ankle), before a period of acclimatisation with a hydraulic ankle prosthesis, after which their gait was reassessed. The focus of the study was directed towards gait loading symmetry, in particular the stance phase duration of the prosthetic and sound limbs.

Method

Components: Non-hydraulic feet, Echelon and Avalon feet.

Measurements: Temporal-spatial gait parameters and plantar pressure (using a Footwork Pro pressure plate)

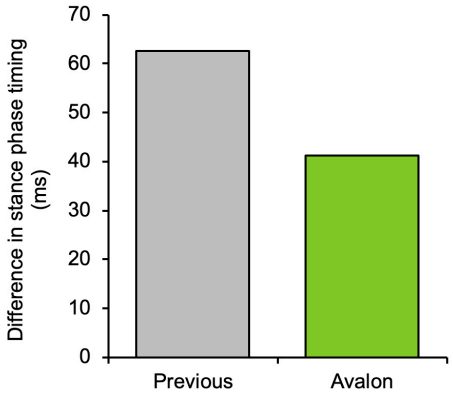
Subjects: Twenty-four lower limb amputees (22 male,2 female). Six excluded, final numbers:
K2: 4 unilateral trans-tibial, 1 bilateral trans-tibial, 3 unilateral trans-femoral
K3: 3 unilateral trans-tibial, 2 bilateral trans-tibial, 3 unilateral trans-femoral

Data collection protocol: Using their current prescription of non-hydraulic feet, amputees were asked to walk, at a self-selected walking speed, for five minutes, back and forth across a 6m level walkway with an integrated pressure platform. This time allowed for a large enough number of eligible steps on the platform. The K2 amputees were prescribed Avalon feet and the K3 amputees were prescribed Echelon feet. A four week acclimatisation period followed for the amputees' newly prescribed prostheses, after which the test protocol was repeated.

Analysis: Paired t-tests to determine significant changes from the before-and-after tests. Stance phase timing was the main outcome measure, with comparisons made between feet, within class of user, and between class.

Results

For all unilateral subjects, the sound side had a longer stance phase duration than the prosthetic side. For bilateral subjects, more time was spent on their "dominant" leg. When using the hydraulic ankle, the difference in the stance phase timing between the sound and prosthetic limbs decreased for 75% of the subjects that completed the study. For the Echelon subjects, six out of eight amputees showed improved symmetry, one saw no difference and the last one showed a symmetry decrease. There was no correlation between change in symmetry and amputation level. The mean stance phase difference was significantly decreased by 21.3ms (p=0.03) representing a 30% improvement. For Avalon subjects, the results were incredibly similar, with six improving, one remaining the same and one showing increased asymmetry. The mean stance phase difference was also reduced by 21.3ms (p=0.02) but due to a greater initial degree of asymmetry for the K2 users, this equated to a 34% improvement.



Conclusion

The author concludes that the results showed a statistically significant reduction in asymmetry of stance phase duration when using prostheses that included a foot with a hydraulic ankle unit. This improvement was irrespective of the patients' activity level. He further states that the results presented indicate that those using hydraulic ankles experience a more symmetrical stance phase duration, with all the benefits that entails, such as decreased sound side loading. He cites studies linking increased sound limb loading to degenerative changes and musculoskeletal problems, including increased risk of osteoarthritis and osteoporosis.

Products with Related Technology:

Linx, Echelon, Elan, EchelonVT, EchelonVAC, Avalon

Mechanical and physiological energetics when using an Echelon hydraulic ankle-foot device in unilateral trans-tibial amputees

Authors: A.R. De Asha[1], G. Askew[2], J. G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK.

[2]School of Biological Sciences, University of Leeds, UK

Presented at: AOPA National Assembly, Las Vegas, NV, USA. September 4-7th 2014.

Summary

The compensatory joint kinetics and metabolic costs of walking were measured for trans-tibial amputees walking at different speeds, using rigid and hydraulic ankle prostheses. It was shown that walking with the hydraulic ankle led to increased walking speed with concurrent reduction in intact-limb compensatory joint work and reduction in the metabolic cost of gait.

Method

Components: Hydraulic ankle-feet (HyAnk – Echelon) and energy-storage-and-return feet (ESR – Esprit)

Measurements: 3D gait analysis; O_2 uptake during walking.

Subjects: Eight unilateral trans-tibial amputees (for gait analysis) and nine unilateral trans-tibial amputees (for metabolic cost measurements).

Data collection protocol: The first set of eight amputees completed level gait analysis trials at their slow, customary and fast walking speeds. The second set of nine amputees walked on a treadmill at various speeds and at 5° and 10° declines (customary speed only). Both groups repeated their protocols with an ESR and a HyAnk.

Analysis: Moments and powers at the distal end of the prosthetic-shank and at the intact joints of both limbs and the metabolic cost of gait were compared between attachment conditions.

Results

Overground: Self-selected walking speed was consistently higher with HyAnk. Consequently, when normalised with regards to speed, the joint work done per metre travelled was significantly reduced by 4% on the sound limb using the HyAnk. Considering the power at the distal end of the socket, the HyAnk removed undesirable energy return in the early to mid-stance region of gait.

Treadmill: There was a reduction in the metabolic costs of gait at all speeds and declines when using the HyAnk (mean reduction of 12%). Reductions were greatest at speeds other than customary. These changes meant that a walking speed of 1.18m/s would be achieved with HyAnk, while for the same amount of effort, only 1.09m/s could be achieved with ESR.

Conclusion

The authors conclude that their findings indicate that compensatory intact-limb joint kinetics and the metabolic costs of gait were reduced when participants used HyAnk compared to an ESR. These changes occurred despite more energy being absorbed, and less returned, by the Echelon during stance.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Toe clearance when walking in people with unilateral trans-tibial amputation: Effects of passive hydraulic ankle

Authors: L. Johnson[1,2], A.R. De Asha1, R. Munjal[3], J. Kulkani[4], J. G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK.

[2]School of Health Studies, University of Bradford, UK

[3]Mobility & Specialised Rehabilitation Centre, Northern General Hospital, Sheffield, UK

[4]Disablement Services Centre, University Hospital of South Manchester, UK

Published in: Journal of Rehabilitation Research and Development (JRRD) 2014; 51(3): 429-438

Summary

The minimum toe clearance (MTC) mechanism in the swing phase of trans-tibial amputee gait was studied. The comparative effects of 2 different foot mechanisms, fixed ankle versus hydraulic ankle were examined.

Method

Components: Trans-tibial prostheses fitted with a range of dynamic response feet with fixed ankles as the habitual foot (habF). The feet exchanged with a hydraulic ankle (hyA-F, Echelon).

Measurements: Kinematics, 3D motion capture gait lab (Vicon).

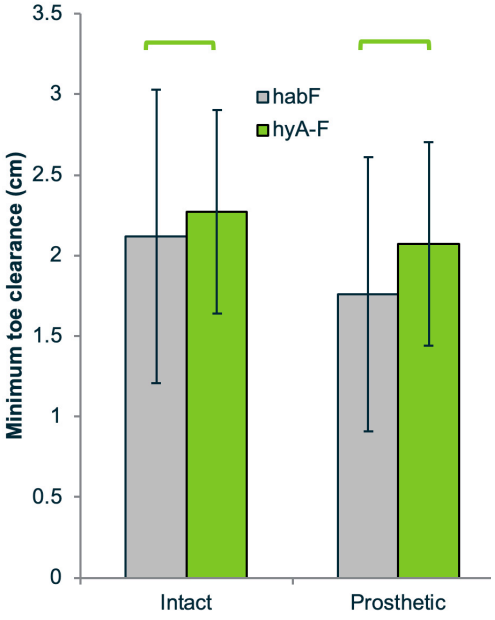
Subjects: 21 active unilateral trans-tibial amputees (18 male, 3 female; 48.2±12.8 years; 87.4±13.2 kg).

Data collection protocol: Prosthetic intervention and exchange of the habF with hyA-F after period of acclimatisation, collected in 2 separate blocks, 10 walking trials at a speed perceived to be comfortable for each foot.

Analysis: 3D kinematic modelling, minimum toe clearance (MTC), repeated measures ANOVA, with post hoc analysis.

Results

Mean MTC was significantly affected by foot type (p= 0.03) and by limb (p = 0.04). MTC increased for both limbs when using a hyA-F compared with habF (2.17 vs 1.90cm) and was also greater on the sound side compared to the prosthetic limb (2.20 vs 1.91 cm). The mean foot angle at MTC was significantly affected by foot type (p=0.01). Mean MTC on the prosthetic was greatest with the hyA-F compared to habF (2.07 vs 1.76cm). The foot angle was reduced (indicating a slightly less toes down angle) on the prosthetic side compared to sound side (-17.7° vs -20.8°). The reduction in foot angle was only significant on the prosthetic side 4.8°). Mean walking speed was significantly greater using the hyA-F compared with when using the habF (p<0.001). Irrespective of foot type there was no significant correlation between walking speed and MTC.



Conclusion

The authors conclude that MTC is increased with use of a hydraulic ankle, and that this may reduce the risk factor for falling. Moreover while increased MTC variability on the prosthetic side was observed it did not contribute to any added increased risk of tripping. The increased MTC is partly driven by the dorsiflexed position of the ankle in swing phase.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Impact on the biomechanics of over ground gait of using an 'Echelon' hydraulic ankle-foot device in unilateral trans-tibial and trans-femoral amputees

Authors: A.R. De Asha[1], R. Munjal[2] J. Kulkani[3], J.G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK

[2]Mobility & Specialised Rehabilitation Centre, Northern General Hospital, Sheffield, UK

[3]Disablement Services Centre, University Hospital of South Manchester, UK

Published in: Clinical Biomechanics 2014; 29: 728-734

Summary

In this paper the dynamics of forwards shank rotation and body centre-of-mass (COM) progression during walking was examined in unilateral trans-tibial and trans-femoral amputees. The effect of ankle foot mechanism on gait progression characteristics was determined.

Method

Components: Trans-tibial and trans-femoral prostheses fitted with a range of dynamic response feet with fixed ankles as the habitual foot (habF) in comparison to a hydraulic ankle (hyA-F, Echelon).

Measurements: Kinematics, 3D motion capture gait lab (Vicon), force plates AMTI.

Subjects: Nineteen K3 lower limb amputees (8 trans-femoral (42±14.8 years; 86.3±15.3kg), 11 trans-tibial (47±10.3 years; 84.5±17.3kg).

Data collection protocol: Prosthetic intervention and exchange of the habF with hyA-F after a period of acclimatisation collected in 2 separate blocks, walking on a level surface at a freely chosen walking speed.

Analysis: Spatio-temporal parameters, COM trajectory, mixed mode repeated measures ANOVA.

Results

When using the hydraulic ankle (hyA-F) both subject groups had a smoother and more rapid progression of the centre-of-pressure beneath the prosthetic hindfoot ($p<0.001$) and a smaller reduction in the centre-of-mass (COM) velocity during prosthetic stance ($p<0.001$). The freely chosen walking speed was higher in both groups when using the hyA-F ($p<0.005$). In both groups stance and swing times and the cadence were unaffected by foot condition. Step length increased bilaterally using the hydraulic device. The effect size differences between foot types was comparable across subject groups.

			Negative COP displacement (cm)	Time COP anterior to shank (% stance)	COM velocity minima during single support (ms^{-1})	Walking speed (ms^{-1})
Trans-tibial	habF	Mean	2.11	34.9	1.01	1.14
		St Dev	(0.97)	(3.5)	(0.15)	(0.14)
	hyA-F	Mean	0.82	31.8	1.09	1.22
		St Dev	(0.64)	(4.1)	(0.15)	(0.11)
Trans-femoral	habF	Mean	1.21	33.7	0.83	0.94
		St Dev	(1.51)	(7.7)	(0.17)	(0.11)
	hyA-F	Mean	0.35	26.9	0.89	0.99
		St Dev	(0.39)	(6.4)	(0.20)	(0.10)

Conclusion

The authors conclude that use of a hydraulic ankle-foot device reduced the foot's "braking" effect (resistance to forwards progression) for both amputee groups. The findings suggest that attenuation of the braking effect from the foot in early stance may be more important to prosthetic-foot function than its ability to return energy in late stance.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Joint loading during graded walking with different prostheses – A case study

Authors: N. Alexander[1], G. Strutzenberger[1], J. Kröll[1], J. Christian[1], T. Wunsch[1] H. Schwameder[1]

[1]Department of Sport Science and Kinesiology, University of Salzburg Hallein, Austria

Presented at: 1st Clinical Movement Analysis World Conference, 23rd Annual Meeting of the European Society for Movement, Analysis in Adults and Children (ESMAC), Rome, Italy. 2014

Summary

This gait analysis study sought to investigate the effects of adaptive hydraulic ankle systems compared to a fixed ankle design when walking at a range of graded inclines, ranging from -12 to +12 degrees.

Method

Components: Dynamic response style foot (Esprit, “ES”), a passive hydraulic ankle (Echelon “EC”) and a microprocessor-controlled hydraulic ankle (Elan “EL”)

Measurements: Kinematics and kinetics, 3D motion capture from 12 cameras (Vicon) and ground reaction forces from 2 force plates (AMTI) built into a hydraulically adjustable ramp walkway.

Subjects: A single unilateral trans-femoral amputee. Microprocessor-controlled knee (Orion).

Data collection protocol: Randomised cross over testing of each foot. At 5 different graded inclines -12°, -4°, 0°, 4° and 12°, data normalisation and reduction 5 clean trials were used for analysis.

Analysis: Gait temporal-spatial parameters, ground reaction forces and lower limb kinematics, kinetics.

Results

The authors report that gait parameters (e.g. temporal spatial data) changed with respect to the grade of inclination, but were not affected by the change in ankle joint design. In most conditions, the joint moments were lowest using EL, with ES producing the largest joint moments in every test condition. On the sound limb the knee joint moments 6-78% higher when using ES compared to the EL. The sound hip extension moments were lowest in every condition using EL. On the residual hip extension moments were 10 times larger with ES compared to EL. The residual hip flexion moments using ES were 40% larger compared to EL.

Conclusion

The study concludes that the greatest changes are seen in joint moment data when examining the effect of ankle-foot function when walking on graded inclines. Joint moments can be up to 10 times larger when using rigid ankle mechanism. The authors conclude that the reduction in joint moments provided by movable ankle joints may be advantageous for use in trans-femoral amputees when walking on graded inclines.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Walking speed related joint kinetic alterations in trans-tibial amputees: impact of hydraulic 'ankle' damping

Authors: A.R. De Asha[1], R. Munjal[2] J. Kulkani[3], J.G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK

[2]Mobility & Specialised Rehabilitation Centre, Northern General Hospital, Sheffield, UK

[3]Disablement Services Centre, University Hospital of South Manchester, UK

Published in: Journal of Neuro Engineering and Rehabilitation (JNER) 2013; 10: 107

Summary

The present study determined whether a trans-tibial prosthesis incorporating a dynamic-response foot that was attached to the shank via an articulating hydraulic device (hyA-F) lessened speed-related adaptations in joint kinetics compared to when the foot was attached via a rigid, non-articulating attachment (rigF).

Method

Components: Trans-tibial prostheses fitted with a range of dynamic response feet with fixed ankles as the habitual foot (habF) in comparison to a hydraulic ankle (hyA-F, Echelon).

Measurements: Kinematics, 3D motion capture gait lab (Vicon), force plates AMTI.

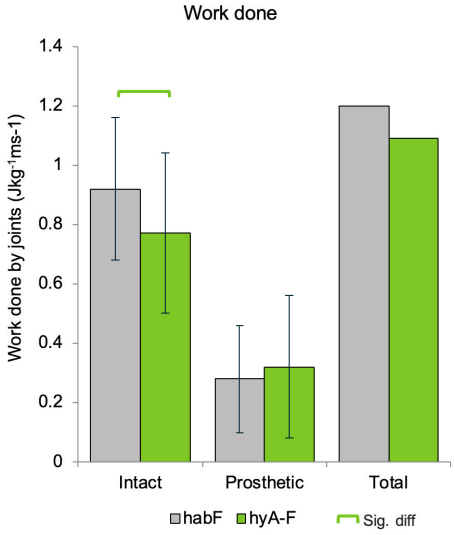
Subjects: Eight, male, unilateral, K3 trans-tibial amputees (44.8±10.7 years; 83.3±19.0kg)

Data collection protocol: Prosthetic intervention and exchange of the habF with hyA-F after period of acclimatisation, collected in 2 separate blocks, walking on a level surface at 3 self-selected speeds, customary, comfortable 'slow' and comfortable 'fast'.

Analysis: Statistical analysis, repeated measures ANOVA, attachment type and speed as repeated factors, post hoc tests.

Results

There was no change in the amount of sound-limb ankle work across speed or attachment conditions. As speed level increased there was an increase on both limbs in the amount of hip and knee joint work done, and increases on the prosthetic side were greater when using the hyA-F. However, because all walking speed levels were higher when using the hyA-F, the sound limb, ankle and combined joint's work per meter travelled were significantly lower (0.77 vs 0.92 $Jkg^{-1}ms^{-1}$, constituting a ~17% reduction); particularly so at the customary speed level (p=0.047). This was the case despite the hyA-F dissipating more energy during stance. Overall no significant increase in total residual joint work was observed. However, the work done per metre travelled increased at the residual knee when using the hyA-F, suggesting increased loading involvement of the prosthetic side.



Conclusion

Findings indicate that a trans-tibial prosthesis incorporating a dynamic-response foot reduced speed related changes in compensatory sound-limb joint kinetics when the foot was attached via an articulating hydraulic device compared to rigid attachment. A reduction (~17%) in muscle related energetics was observed suggesting the physical demands of walking were reduced with use of a hydraulic ankle. The authors conclude that in view of measured adaptation to joint kinetics "energy return" per se is not necessarily the key design criterion for a prosthetic foot.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Patient evaluation of the Echelon foot using the Seattle Prosthesis Evaluation Questionnaire

Authors: I. Sedki[1], R. Moore[1]

[1]Luton and Dunstable Hospital NHS Foundation Trust, Luton UK

Published in: Prosthetics and Orthotics International 2013; 37(3): 250-254

Summary

In this case report, the clinical impact and user satisfaction levels when using a hydraulic ankle foot system compared to a non-hydraulic foot system was examined for different amputation levels.

Method

Components: Echelon hydraulic ankle-foot, compared to either Esprit or Multiflex foot.

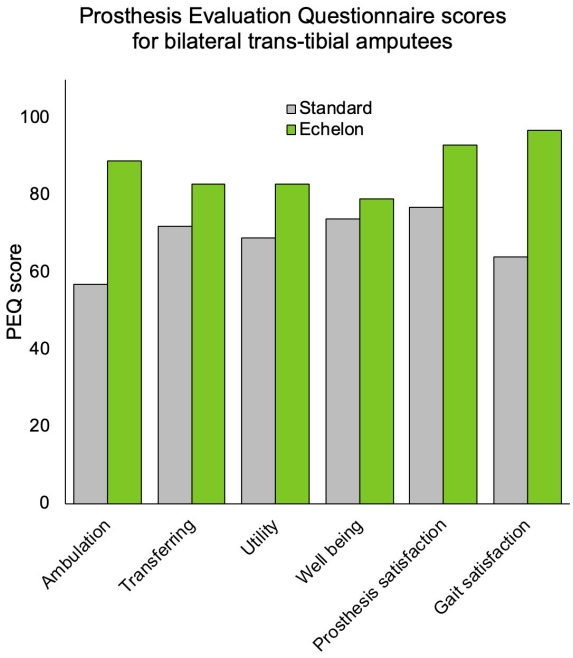
Measurements: Seattle Prosthesis Evaluation Questionnaire (PEQ).

Subjects: 9 male patients (3 unilateral trans-tibial, 3 trans-femoral, 3 bilateral trans-tibial; 42-62 years).

Data collection protocol: Patients were asked to evaluate their current foot (Esprit, Multiflex), then again 4 weeks post fitting using the Echelon.

Results

Statistically significant increases in satisfaction were found in most PEQ assessment domains with the largest improvements for ‘ambulation satisfaction’ (+16.7 points), ‘prosthesis satisfaction’ (+19.6 points) and ‘gait satisfaction’ (+25.3 points), all $p<0.01$. The largest magnitude of improvement was reported by the bilateral amputee group with a 33.4 point improvement in gait satisfaction.



Conclusion

Use of a hydraulic ankle improves patient levels of satisfaction across amputation levels. In particular, the use of hydraulic self-aligning ankles should be considered in all bilateral cases where the patient is able to achieve outdoor walking.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Attenuation of centre-of-pressure trajectory fluctuations under the prosthetic foot when using an articulated hydraulic ankle attachment compared to fixed attachment

Authors: A.R. De Asha[1], L. Johnson[1,2], R. Munjal[3], J. Kulkarni[4], J.G. Buckley[1]

[1]Division of Medical Engineering, School of Engineering, Design and Technology, University of Bradford, UK

[2]School of Health Studies, University of Bradford, UK

[3]Mobility & Specialized Rehabilitation Centre, Northern General Hospital, Sheffield, UK

[4]Disablement Services Centre, University Hospital of South Manchester, UK

Published in: Clinical Biomechanics 2013; 28(2): 218-224

Summary

The centre-of-pressure (COP) trajectory reflects how body weight is transferred over the ankle during walking and is governed by foot and ankle design. This study sought to investigate whether COP disruptions often symptomatic as a 'dead spot' in rollover are reduced when using an articulating hydraulic ankle.

Method

Components: Habitually used, dynamic response feet, with rigid, semi-rigid attachments and a hydraulic visco-elastic foot (Echelon).

Measurements: Kinematics and kinetics, opto-electronic motion capture (Vicon) and ground reaction force plates (AMTI).

Subjects: Twenty physically active trans-tibial amputees (47.4±12 years; 87.3±13.5kg).

Data collection protocol: P2 blocks of 10 walking trials with each foot counter-balanced across participants. All tests at freely selected comfortable walking speed.

Analysis: Temporal-spatial parameters and lower limb kinematics, COP trajectory and velocity.

Results

The magnitude of the peak negative COP velocity was reduced ($p<0.001$) and the distance travelled posteriorly was reduced ($p=0.001$) with use of the hydraulic foot and ankle. The mean angular velocity of the prosthetic shank during double support was significantly increased ($p<0.001$). Mean freely selected comfortable walking speed increased ($p=0.001$) with use of the hydraulic ankle.

		Negative COP displacement (m)	Max negative COP velocity (ms^{-1})	Mean COP velocity variability in single support (ms^{-1})	Shank mean angular velocity in single support ($°s^{-1}$)	Walking speed (ms^{-1})
habF	Mean	-0.022	-0.153	0.273	94.5	1.12
	St Dev	(0.018)	(0.110)	(0.070)	(20.2)	(0.14)
hyA-F	Mean	-0.010	-0.043	0.210	101.7	1.17
	St Dev	(0.008)	(0.066)	(0.063)	(19.2)	(0.15)

Conclusion

The alteration to the COP trajectories, the increased angular shank velocity and the increase in freely selected customary speed suggest that the hydraulic ankle reduces the "braking" effect in roll-over of non-hydraulic foot in a way that may be functionally beneficial for active amputees.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC

Kinematics, kinetics and internal mechanical stresses of trans-tibial amputees walking and climbing stairs with hydraulic feet

Authors: A. Kristal[1], S. Portnoy[2], A. Gefen[2], U. Givon, Z. Yizhar, Z. Dvir, H. Sharon[3], I. Siev-Ner[1]

[1]Department of Orthopaedic Rehabilitation, Chaim Sheba Medical Centre, Israel

[2]Department of Biomedical Engineering, Tel Aviv University, Ramat Aviv, Israel

[3]Physical Therapy Department, Chaim Sheba Medical Centre, Israel

Published in: Orthopädie + Reha-Technik 2012; 3-6

Summary

This study sought to examine the efficiency, safety and comfort of a hydraulic ankle-foot with unilateral trans-tibial amputees for level ground and stair walking.

Method

Components: Hydraulic foot and ankle system (Echelon), user's habitual non-hydraulic foot and ankle.

Measurements: Kinematics and kinetics, opto-electronic motion capture (CODA-3D), four force plates. In-socket pressure measurement system.

Subjects: 10 active, unilateral trans-tibial amputees (43±12 years; 78±11kg).

Data collection protocol: Two test sessions, (i) using habitual foot, (ii) with the hydraulic foot, walking at comfortable self-selected speed and ascending and descending 4 steps.

Analysis: Kinematic analysis of sagittal hip, knee and ankle joints, kinetic joint moments and powers.

Results

In comparison to the habitual foot when using the hydraulic the ankle, the foot was dorsiflexed during swing phase. Additionally, less hip flexion was measured during initial contact and during the swing phase. Increased ankle plantarflexor moment and power was measured with the hydraulic foot. Peak internal stresses at the distal residuum were also reduced ($p<0.01$).

Conclusion

The authors conclude that use of the hydraulic foot results in less compensation at the hip and knee enabling a smoother posterior-anterior acceleration path. The reduction in stresses measured at the residuum is thought to lower the risk of internal injury of the soft tissues of the residuum.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Einfluss der Eigenschaften eines Prothesenfusses auf das Gangbild von Unterschenkel-Amputierten – Influence of the characteristics of a prosthetic foot on the gait of trans-tibial amputees

Authors: M. Erler[1], F. Layer, K. Sander, K. Erler, H. Ziegenthaler

[1]Technische Hochschule Mittelhessen

Published in: Medizinische-Orthopädische Technik 2012; 1: 57-59

Summary

The impact of different prosthetic foot design on the gait of trans-tibial amputees was assessed using kinematic, kinetic and EMG measurements. Further balance tests and patient centred assessments were conducted. The assessment showed objective and subjective advantages of the test hydraulic ankle-foot compared to the patients habitually used ankle-foot.

Method

Components: Echelon, patient's own non-hydraulic foot

Measurements: Gait analysis system (Vicon 460), bi-polar surface EMG (biovision), balance tests (static and dynamic balance) and patient centred assessment.

Subjects: Thirteen K2-K4 trans-tibial amputees (2 female, 11 male; 48.7±11.8 years)

Data collection protocol: All investigations were undertaken with the own foot of the subject and Echelon. Kinetic and kinematic parameters as well as muscle activity were recorded walking on level ground at self-selected speed. Tests to assess static and dynamic balance were undertaken. A questionnaire evaluation was also undertaken.

Analysis: After reduction to study relevant parameters with PASW 18, a data analysis was conducted.

Results

The test foot showed a reduction of stance phase duration, an increase of stride length in the amputated side and a reduction of knee joint movement. Plantarflexion moment was increased, dorsiflexion moment and absorbed/generated hip energy was reduced. Cadence decreased and the stride time increased. EMG data of the test foot was closer to a physiological intramuscular coordination pattern. Better results were achieved in the balance test using the test foot. The patient-centred assessment showed that the test foot was perceived as more secure, comfortable and less strenuous in different walking situations of daily living.

Conclusion

The test foot seems to have a positive impact on energy balance, cadence and cycle time. Energy reduction of up to 23.7% per step was achieved in the hip joint. Also in subjective evaluation it seemed to be advantageous for activities of daily living (ADL) and to reduce the exhaustion during walking. Intramuscular activities came closer to the pattern of able-bodied people using the test foot. According to the authors this might relieve the contralateral limb and spinal cord and increase the quality of life.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Outdoor dynamic subject-specific evaluation of internal stresses in the residual limb: Hydraulic energy-stored prosthetic foot compared to conventional energy-stored prosthetic feet

Authors: S. Portnoy[1], A. Kristal[2], A. Gefen[1], I. Siev-Ner[2]

[1]Department of Biomedical Engineering, Tel Aviv University, Israel

[2]Department of Orthopaedic Rehabilitation, Chaim Sheba Medical Centre, Tel Hashomer, Israel

Published in: Gait and Posture 2012; 35(1): 121-5

Summary

The pressure between the prosthetic socket and stump of nine trans-tibial amputees was measured during a range of walking activities, with conventional energy storage and return feet and with a hydraulic ankle foot. The authors found significantly lower pressures with the Echelon compared to the other feet, which they attribute to the hydraulic mechanism. They suggest the Echelon may help protect against deep tissue injury in trans-tibial amputees.

Method

Components: Echelon foot and the subjects' own energy-storage-and-return feet (3x Trias, 1x Venture, 2x Trustep, 1x C-walk, 1x Pathfinder and 1x Esprit were used).

Measurements: Socket interface pressure measured using a 3-element FlexiForce thin film sensor (Tekscan).

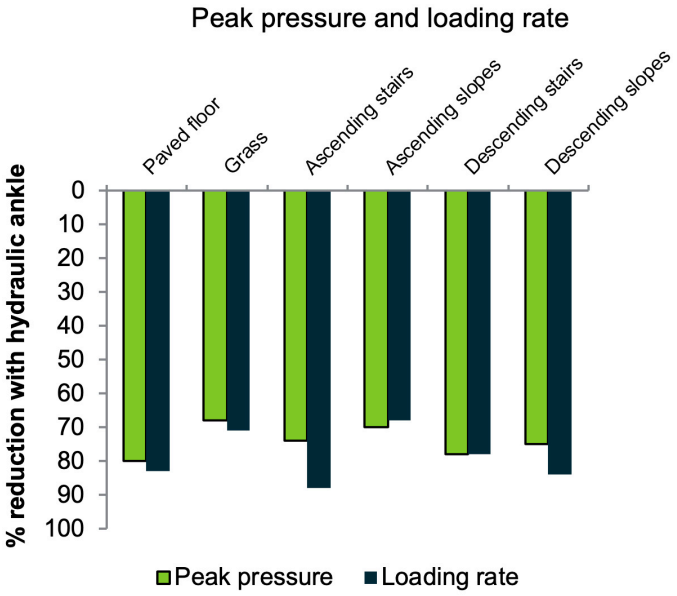
Subjects: Nine male unilateral traumatic trans-tibial amputees, with 6 to 36 post amputation and a mean age of 42.7 years.

Data collection protocol: Subjects wore their own prosthetic feet and were asked to walk at their natural speed for 1 minute on a paved surface indoors, followed by a slope ascent and descent outdoors, then 1 minute walking on grass plus a stair ascent and descent outdoors. Pressure measurements were logged in real-time. Subjects were then fitted with an Echelon foot, which they used for 1 month before being invited back to repeat the measurements. Subjects were also interviewed at the end of the study.

Analysis: Five subsequent steps were taken from each walking trial. Parameters of interest included: Cadence, the averaged peak and RMS internal von Mises stresses, and the loading rate (calculated). Loading rate was defined as the ratio of peak stress over the time interval from heel strike to peak stress.

Results

All subjects were satisfied with the Echelon, with no reports of abnormal pressure or discomfort. There was a significant decrease in peak stress and loading rate with the Echelon (the loading was at least 3 times lower). The internal stresses decreased with the Echelon significantly whilst on the paved floor and ascending stairs.



Conclusion

The authors attribute the reduction in stress to the hydraulic ankle mechanism. Loads transferred more slowly, preventing sudden impacts. Residuum less likely to be injured, hence the hydraulic design may protect against deep tissue injury. The energy storage and return feet users may be compensating for high stress impacts elsewhere in their gait.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Prosthetic-limb ankle kinetics, energy storage and return when using a hydraulic ankle device in unilateral trans-tibial amputees

Authors: A.R. De Asha[1], L. Johnson[1], J. Kulkani[2], R. Munjal[3], J.G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK

[2]Disablement Service Centre, University Hospital of South Manchester, Manchester, UK

[3]Mobility & Specialised Rehabilitation Centre, North General Hospital, Sheffield, UK

Presented at: Joint World Congress of ISPGR and Gait and Mental Function, Trondheim, Norway. June 24-28th 2012

Summary

This study sought to investigate biomechanical differences with use of conventional rigid and semi-rigid dynamic response feet in comparison to hydraulic viscoelastic designs.

Method

Components: Dynamic response feet, 15 with a rigid attachment, 5 semi-rigid and a hydraulic visco-elastic foot (Echelon).

Measurements: Kinematics and kinetics, opto-electronic motion capture and ground reaction force plates.

Subjects: Twenty active, unilateral trans-tibial amputees.

Data collection protocol: Cross-over protocol design, 10 trials captured for habitual foot, and 10 captured for the hydraulic ankle foot (Echelon).

Analysis: Stance phase kinetics were determined using standard inverse dynamic modelling and analysis.

Results

With use of the visco-elastic hydraulic foot; the moment transition sign from plantar-dorsiflexion moment occurred 10% earlier in the stance phase ($p = 0.035$). The energy rebound from heel-keel recoil reduced by 68% ($p = 0.035$). COP peak negative velocity ($p < 0.001$) and backwards displacement reduced ($p = 0.002$). Roll-over radius reduced by 25% ($p = 0.007$) from 0.168±0.053m to 0.123±0.045m. Forwards angular velocity of the shank during double support (onto prosthesis) increased ($p=0.001$). Walking speed increased from 1.12±0.14ms^{-1} to 1.17±0.15ms^{-1} ($p = 0.002$).

Conclusion

The authors conclude that the ankle moment transition timing and reduced mid stance energy rebound to be more reflective of able-bodied gait. Moreover the increased angular velocity of the shank, less disrupted COP progression, and reduced roll-over radius are thought by the authors to be contributing factors to the observed increase in self-selected normal speed and improved progression of the centre-of-mass over the prosthetic limb. Overall the authors conclude that use of a hydraulic ankle-foot device offer biomechanical benefits making mid stance kinetics more akin to able-bodied.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Outdoor biomechanical evaluation of a hydraulic prosthetic foot

Authors: I. Siev-Ner[1], A. Kristal[1], H. Sharon[2], A. Gefen[3], S. Portnoy[3]

[1]Department of Orthopaedic Rehabilitation, Chaim Sheba Medical Centre, Israel

[2]Physical Therapy Department, Chaim Sheba Medical Centre, Israel

[3]Department of Biomedical Engineering, Tel Aviv University, Ramat Aviv, Israel

Published in: Proceedings of the Journal of Prosthetics and Orthotics, 2011

Summary

The internal socket interface pressures of trans-tibial amputees were compared for hydraulic and non-hydraulic ankle-foot systems whilst ambulating on different surfaces.

Method

Components: Hydraulic foot and ankle system (Echelon), user habitual non hydraulic foot and ankle.

Measurements: Validated internal stress monitor (Flexiforce, Tekscan), to quantify stresses at the tibial end.

Subjects: Nine active, male unilateral trans-tibial amputees (42±12 years; 78±12kg).

Data collection protocol: Each subject walked on inclines, stairs and different level surfaces, using their own foot and again a month after fitting a hydraulic ankle-foot.

Analysis: Data from 5 consecutive steps for each test condition were averaged and the root mean square (RMS) internal von Mises stresses and the loading rates were calculated.

Results

The peak internal stresses and loading rates were significantly lower ($p<0.01$) for all test conditions with the hydraulic foot compared to the user's own prosthetic foot.

Conclusion

The lower loading rates were attributed to the hydraulic ankle mechanism, allowing loads to be transferred to the residuum more slowly, thus preventing high impacts and resulting in lower internal stresses.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Evaluation of a Hydraulic Prosthetic Foot While Standing on Slopes

Authors: A. Kristal[1], S. Portnoy[2], O. Elion[3], H. Sharon[4], A. Gefen[2], I. Siev-Ner[1]

[1]Department of Orthopaedic Rehabilitation, Chaim Sheba Medical Centre, Israel

[2]Department of Biomedical Engineering, Tel Aviv University, Ramat Aviv, Israel

[3]The CAREN VR lab, Chaim Sheba Medical Centre, Israel

[4]Physical Therapy Department, Chaim Sheba Medical Centre, Israel

Published in: Proceedings of the Journal of Prosthetics and Orthotics, 2011

Summary

The efficiency of hydraulic and non-hydraulic foot systems for standing and balancing on inclined surfaces was studied.

Method

Components: Hydraulic foot and ankle system (Echelon), user habitual non hydraulic foot and ankle.

Measurements: Kinematic and Kinetic, opto-electronic motion capture (Vicon). Computer controlled titling platform equipped with 2 force plates.

Subjects: Ten active, unilateral trans-tibial amputees (43±12 years; 78±11kg).

Data collection protocol: Each subject stood on the force plate, which was tilted dynamically forwards (10°, for 20s) and backwards (10°, for 20s) and returned to level for 30 seconds. Test repeated 3 times with each foot.

Analysis: Kinematic analysis of sagittal knee and foot ankle, kinetic analysis of vertical forces and centre-of-pressure (COP) trajectory.

Results

The hydraulic ankle enabled a larger range of ankle flexion; this resulted in a decrease in sagittal knee fluctuations in both legs. The COP trajectories were more centralized with the hydraulic foot.

Conclusion

The hydraulic ankle was shown to improve standing, balance control and stability.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Effects of a hydraulic ankle on gait function and symmetry in unilateral lower limb amputees

Authors: A.R. De Asha[1], L. Johnson[1], J. Kulkani[2], R. Bose[2], G. Bavikatte[2], A. McKendrick[2], J.G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK

[2]Disablement Service Centre, University Hospital of South Manchester, Manchester, UK

Presented at: International Society for Prosthetics and Orthotics (ISPO) UK. Annual Scientific Meeting Compendium 7-8th October 2011, Hammersmith Hospital, London

Summary

This study sought to investigate the effects of a hydraulic ankle system compared to a fixed ankle in unilateral amputees in terms of gait function and symmetry during over-ground walking in unilateral trans-tibial and trans-femoral amputees.

Method

Components: Dynamic response feet, with rigid and semi attachments and a hydraulic visco-elastic foot (Echelon).

Measurements: Kinematics and kinetics, opto-electronic motion capture (Vicon) and ground reaction force plates (AMTI).

Subjects: Ten physically active amputees (6 trans-tibial, 4 trans-femoral; 43.9±13.1 years; 84.4±11.8 kg).

Data collection protocol: randomised cross over design, 10 “clean” trials using each foot at user self-selected speed were used for analysis.

Analysis: randomised cross over design, 10 “clean” trials using each foot at user self-selected speed were used for analysis.

Results

For the TT group use the hydraulic ankle increased step length significantly from 0.7m to 0.73m ($p=0.004$). Stride length increased significantly for both TT amputees ($p=0.037$) and TF amputees ($p=0.046$). Peak hip prior to initial contact flexion increased in all subjects on the prosthetic side (4.6° TT, $p = 0.046$, 4.9° TF) as a result differences between sides (hip asymmetry) reduced from 1.5° to 0.95° (TT) and from 4.0 to 2.45° (TF). There was no significant change in hip extension during terminal stance/pre-swing. There were no significant changes in the magnitudes of GRFs in early or late stance, however the centre-of-pressure (COP) passed anterior to the base of the prosthetic shank earlier in stance phase for all subjects (22% from 32% TT, $p=0.028$, 23% from 24% TF*).

Conclusion

The increase in hip flexion on the prosthetic side improved gait symmetry. The more rapid anterior progression of the COP is more reflective of able-bodied gait, together with the kinematic changes explain why participants reported subjective gait improvements whilst being able to increase step length.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Roll-over characteristics and ankle joint kinetics using low-profile dynamic response foot with a fixed versus hydraulic ankle in trans-tibial amputees

Authors: S.J. Brown[4], A.R. De Asha[1], L. Johnson[1], J. Kulkani2, R. Munjal[3], J.G. Buckley[1]

[1]School of Engineering, Design and Technology, University of Bradford, UK

[2]Disablement Service Centre, University Hospital of South Manchester, Manchester, UK

[3]Mobility & Specialised Rehabilitation Centre, North General Hospital, Sheffield, UK

[4]Institute for Biomedical Research into Human Movement and Health, Manchester Metropolitan University

Presented at: International Society for Prosthetics and Orthotics (ISPO) UK. Annual Scientific Meeting Compendium 7-8th October 2011, Hammersmith Hospital London

Summary

This study reports on gait analysis including roll-over shape analysis conducted to investigate changes in amputee gait when using a conventional dynamic response foot design compared to a hydraulic visco-elastic foot design.

Method

Components: Dynamic response foot (Esprit), hydraulic visco-elastic foot (Echelon).

Measurements: Opto-electronic motion capture system with ground reaction force plates.

Subjects: Four trans-tibial amputees (37.3±3.3 years; 74.8±10 kg).

Data collection protocol: Randomised cross over study, design testing of each foot at self-selected comfortable walking speed.

Analysis: Standard inverse dynamics modelling and analysis of joint moment and powers. Analysis of roll-over shapes.

Results

Reduction to the radius of the roll-over shape ($p = 0.05$) when using the hydraulic ankle. With use of the hydraulic ankle the transition from dorsiflexion moment to plantarflexion occurred earlier in the stance phase (by 9%, $p=0.018$). The dorsiflexion moment impulse was reduced by 40% ($p=0.044$) and the energy returned during this time was reduced by 68% ($p=0.035$); with peak positive power reduced by 50%. During mid to late stance, there were no significant differences in the peak plantarflexion moments or peak negative or positive powers or in the timings of when these occurred.

Conclusion

The authors conclude that the use of a hydraulic device attenuates the “recoil-effect” of the heel keel during the second rocker. Moreover, as there were no differences in the ankle kinetics during mid-late stance the reduced roll-over radius was likely due to the centre-of-mass (COM) being transferred onto the prosthetic limb in a smoother manner.

Products with Related Technology:

Linx, Elan, Echelon, EchelonVT, EchelonVAC, Avalon

Bibliography

1. Wurdeman SR, Stevens PM, Campbell JH. Mobility analysis of AmpuTees (MAAT 5): Impact of five common prosthetic ankle-foot categories for individuals with diabetic/dysvascular amputation. J Rehabil Assist Technol Eng 2019; 6: 2055668318820784.
2. McGrath M, Moser D, Baier A. Anforderungen an eine geeignete Prosthesentechnologie für ältere, dysvaskuläre Amputierte - Requirements of a suitable prosthesis technology for elderly, dysvascular amputees. Orthop-Tech. 2019; 11: 42-46.
3. Askew GN, McFarlane LA, Minetti AE, Buckley JG. Energy cost of ambulation in trans-tibial amputees using a dynamic-response foot with hydraulic versus rigid 'ankle': insights from body centre-of-mass dynamics. J NeuroEngineering Rehabil 2019; 16: 39.
4. Bai X, Ewins D, Crocombe AD, Xu W. A biomechanical assessment of hydraulic ankle-foot devices with and without micro-processor control during slope ambulation in trans-femoral amputees. PLOS ONE 2018; 13: e0205093.
5. Kannenberg A. Evidence on prosthetic feet with active dorsiflexion feature, passive microprocessor control and active ankle power generation: a mini literature review. Can Prosthet Orthot J; 1.
6. McGrath M, Laszczak P, Zahedi S, Moser D. Microprocessor knees with "standing support" and articulating, hydraulic ankles improve balance control and inter-limb loading during quiet standing. J Rehabil Assist Technol Eng 2018; 5: 2055668318795396.
7. McGrath M, Laszczak P, Zahedi S, Moser D. The influence of a microprocessor-controlled hydraulic ankle on the kinetic symmetry of trans-tibial amputees during ramp walking: a case series. J Rehabil Assist Technol Eng 2018; 5: 2055668318790650.
8. Abdulhasan ZM, Scally AJ, Buckley JG. Gait termination on a declined surface in trans-femoral amputees: Impact of using microprocessor-controlled limb system. Clin Biomech 2018; 57: 35–41.
9. Moore R. Effect of a Prosthetic Foot with a Hydraulic Ankle Unit on the Contralateral Foot Peak Plantar Pressures in Individuals with Unilateral Amputation. JPO J Prosthet Orthot 2018; 30: 165–170.
10. Barnett CT, Brown OH, Bisele M, Brown MJ, De Asha AR, Strutzenberger G. Individuals with Unilateral Trans-tibial Amputation and Lower Activity Levels Walk More Quickly when Using a Hydraulically Articulating Versus Rigidly Attached Prosthetic Ankle-Foot Device. JPO J Prosthet Orthot 2018; 30: 158–64.
11. Alexander N, Strutzenberger G, Kroell J, Barnett CT, Schwameder H. Joint Moments During Downhill and Uphill Walking of a Person with Trans-femoral Amputation with a Hydraulic Articulating and a Rigid Prosthetic Ankle—A Case Study. JPO J Prosthet Orthot 2018; 30: 46–54.
12. Bai X, Ewins D, Crocombe AD, Xu W. Kinematic and biomimetic assessment of a hydraulic ankle-foot in level ground and camber walking. PLOS ONE 2017; 12: e0180836.
13. Dotan-Moram Y, Portnoy S, Kristal A, Sharon H, Siev-Ner I. Gait characteristics in trans-tibial amputees ambulating with and without a microprocessor-controlled hydraulic prosthetic ankle. In: ISPO World Congress. Cape Town, South Africa, 2017.
14. De Asha AR, Barnett CT, Struchkov V, Buckley JG. Which Prosthetic Foot to Prescribe?: Biomechanical Differences Found during a Single-Session Comparison of Different Foot Types Hold True 1 Year Later. JPO J Prosthet Orthot 2017; 29: 39–43.
15. Moore R. Patient Evaluation of a Novel Prosthetic Foot with Hydraulic Ankle Aimed at Persons with Amputation with Lower Activity Levels. JPO J Prosthet Orthot 2017; 29: 44–47.
16. Struchkov V, Buckley JG. Biomechanics of ramp descent in unilateral trans-tibial amputees: Comparison of a microprocessor controlled foot with conventional ankle–foot mechanisms. Clin Biomech 2016; 32: 164–170.
17. Moore R. Effect on Stance Phase Timing Asymmetry in Individuals with Amputation Using Hydraulic Ankle Units. JPO J Prosthet Orthot 2016; 28: 44–48.
18. De Asha AR, Askew G, Buckley JG. Mechanical and physiological energetics when using an Echelon hydraulic ankle-foot device in unilateral trans-tibial amputees. In: American Orthotics and Prosthetics Association National Assembly. Las Vegas, NV, USA, 2014.
19. Johnson L, De Asha AR, Munjal R, Kulkarni J, Buckley JG. Toe clearance when walking in people with unilateral trans-tibial amputation: effects of passive hydraulic ankle. J Rehabil Res Dev 2014; 51: 429.
20. De Asha AR, Munjal R, Kulkarni J, Buckley JG. Impact on the biomechanics of overground gait of using an 'Echelon' hydraulic ankle–foot device in unilateral trans-tibial and trans-femoral amputees. Clin Biomech 2014; 29: 728–734.
21. Alexander N, Strutzenberger G, Kroell J, Christian J, Wunsch T, Schwameder H. Joint loading during graded walking with different prostheses–a case study. In: 1st Clinical Movement Analysis World Conference, 23rd Annual Meeting of the European Society for Movement Analysis in Adults and Children (ESMAC). Rome, Italy, 2014.
22. De Asha AR, Munjal R, Kulkarni J, Buckley JG. Walking speed related joint kinetic alterations in trans-tibial amputees: impact of hydraulic 'ankle' damping. J Neuroengineering Rehabil 2013; 10: 1.
23. Sedki I, Moore R. Patient evaluation of the Echelon foot using the Seattle Prosthesis Evaluation Questionnaire. Prosthet Orthot Int 2013; 37: 250–254.
24. De Asha AR, Johnson L, Munjal R, Kulkarni J, Buckley JG. Attenuation of centre-of-pressure trajectory fluctuations under the prosthetic foot when using an articulating hydraulic ankle attachment compared to fixed attachment. Clin Biomech 2013; 28: 218–224.

25. Kristal A, Portnoy S, Gefen A, Givon U, Yizhar Z, Dvir Z, Sharon H, Siev-Ner I. Kinematics, kinetics and internal mechanical stresses of trans-tibial amputees walking and climbing stairs with hydraulic feet. In: Orthop Reha-Tech. 2012

26. Erler M. Einfluss der Eigenschaften eines Prothesenfußes auf das Gangbild von Unterschenkelamputierten. Doctoral dissertation, Diplomarbeit im Studiengang Orthopädie-und Rehatechnik, Technische Hochschule Mittelhessen, Gießen, 2011.

27. Portnoy S, Kristal A, Gefen A, Siev-Ner I. Outdoor dynamic subject-specific evaluation of internal stresses in the residual limb: hydraulic energy-stored prosthetic foot compared to conventional energy-stored prosthetic feet. Gait Posture 2012; 35: 121–125.

28. De Asha AR, Johnson L, Kulkarni J, Munjal R, Buckley JG. Prosthetic-limb ankle kinetics, energy storage and return when using a hydraulic ankle device in unilateral trans-tibial amputees. In: Joint World Congress of ISPGR and Gait and Mental Function. Trondheim, Norway, 2012.

29. Siev-Ner I, Kristal A, Sharon H, Gefen A, Portnoy S. Outdoor biomechanical evaluation of a hydraulic prosthetic foot. In: American Academy of Orthotists and Prosthetists - 37th Academy Annual Meeting and Scientific Symposium. Orlando, Florida, USA, 2011.

30. Kristal A, Portnoy S, Elion O, Sharon H, Gefen A, Siev-Ner I. Evaluation of a hydraulic prosthetic foot while standing on slopes. In: American Academy of Orthotists and Prosthetists - 37th Academy Annual Meeting and Scientific Symposium. Orlando, Florida, USA, 2011.

31. De Asha AR, Johnson L, Kulkarni J, Bose R, Bavikatte G, McKendrick A, Buckley JG. Effects of a hydraulic ankle on gait function and symmetry in unilateral lower limb amputees. In: International Society for Prosthetics and Orthotics (ISPO) UK. Annual Scientific Meeting. Hammersmith Hospital, London, UK, 2011.

32. Brown S, De Asha AR, Johnson L, Kulkarni J, Munjal R, Buckley JG. Roll-over characteristics and ankle joint kinetics using low-profile dynamic response foot with a fixed versus hydraulic ankle in trans-tibial amputees. In: International Society for Prosthetics and Orthotics (ISPO) UK Annual Scientific Meeting. Hammersmith Hospital, London, UK, 2011.

+44 (0) 1256 316600 | customer.service@blatchford.co.uk | @blatchfordgrp | blatchford.co.uk

435968939 Iss1 01/20. Information correct at time of print.