Clinical Studies Compendium

Ankle-foot edition 2 (2011-2014)

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Foreword

This second edition compendium provides a summary of the independent scientific studies relating to Endolite hydraulic ankle-foot products. Of interest to patients, clinicians and health care providers, it provides an overview of all published scientific product evaluation to date. This updated edition includes four new peer-reviewed papers published in the last two years. Endolite did not sponsor or fund the research presented here, nor did it have any role in the analysis and reporting of the findings. 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.

Biomimetic Hydraulic Technology

The engineering of nature is the prime source of inspiration at the heart of Endolite's biomimetic design philosophy. Its hydraulic-ankle-foot systems, Echelon™, EchelonVT™ and Elan™ are products of this approach.

A core technology of these award winning innovations is the application of visco-elastic, hydraulic control at the ankle joint to match normal ankle movement during gait. This is created by the use of spring-damper actuators arranged in series to control ankle-foot plantar and dorsiflexion movements. Compared to predominantly elastic ankle-foot mechanisms, the unique properties of this technology more accurately match the dynamic and adaptive qualities of muscle actuation and thus natural joint motion.

The independent studies demonstrate the evidence of visco-elastic dampening which is present across the family of Endolite hydraulic ankles including Elan, Echelon, EchelonVT and Avalon.

Validation

The pathologies of amputee locomotion are well known. The asymmetrical loading between limbs is a risk factor for long term joint disease. Care and management of tissue loading at the residuum is also critical. Resolution of both of these issues can be considered a medical care necessity. Additionally, comfort is almost universally recognised as being the single biggest factor determining amputee satisfaction with their prosthesis.

Ankle-foot design is a central factor in these issues, since the forces generated between the foot and ground are ultimately directed to the socket interface via the prosthesis mechanism. For these reasons a key aim of Endolite's design approach is to enable the prosthesis to work in a more natural and effective way, while loading the residuum more sympathetically.

Fourteen independent research studies are detailed, along with an overview of study design and clinical interpretation. In comparison to the non-hydraulic feet tested, Endolite hydraulic ankle-feet were shown to:

- Enable more evenly balanced loading between limbs and greater involvement of the prosthetic side
- Reduce intact side muscle compensation
- Increase comfort and reduce socket interface loading
- Improve balance and stability when standing on varied surfaces
- Reduce net joint moments when walking on graded inclines
- Improve safety and reduction of the risk of trips and falls from increased toe clearance by the device
- Enable greater patient mobility
- Improve biomechanical gait efficiency and progression of movement, enabling faster self-selected walking speed
- Improve lower limb muscle energetics (~17% reduction in energy cost)
- Increase patient satisfaction with prosthesis usage

Contents

Studies Overview

Study Design and Measurement	Johnson 2014	De Asha 2014	Alexander 2014	De Asha 2013	Kristal 2012	Erler 2012	Sedki 2013	De Asha 2012	Portnoy 2012	De Asha 2012	Siev-Ner 2011	Kristal 2011	De Asha 2011	Brown 2011
Kinematics	●	●	●		●	●		●		●		●	●	●
Kinetics		●	●	●	●	●		●		●		●	●	●
Socket Pressure					●				●		●			
Temporal Spatial	●	●	●			●		●						
EMG						●								
Psychometric Assessment						●	●							
Clinical interpretation														
Safety, Improved balance[1]												●		
Safety, Reduced risk of falls[2]	●				●							●		
Patient Satisfaction[3]						●	●	●	●		●		●	
Gait Progression/efficiency[4]		●	●	●	●	●	●	●		●			●	●
Gait Quality[5]			●	●	●		●	●		●		●	●	●
Gait Symmetry[6]				●		●						●	●	
Reduced socket interface stress[7]					●				●		●			

Key Notes:

1 Where results are indicative of increased safety and reduced risk of falling from improved balance.

2 Results indicative of improved safety and reduced risk of tripping, from improved toe clearance in swing phase.

3 Clinical outcome demonstrating improved patient satisfaction with prosthesis use and performance.

4 Where results show biomechanical improvement to the efficiency of transporting body mass.

5 Results which demonstrate a reduction to pathological gait compensation, e.g. results tending towards normal healthy gait characteristics.

6 Findings which indicate less loading asymmetries between limbs, for example, potentially reducing the risk of degenerative joint disease development.

7 Results strongly associated with comfort, e.g. reduction in socket loading stress with prosthesis use, reduced potential for residuum tissue damage.

Toe clearance when walking in people with unilateral transtibial amputation: Effects of passive hydraulic ankle

Authors: L. Johnson[1/2], A.R. De Asha[1], 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 transtibial amputee gait was studied. The comparative effects of 2 different foot mechanisms, fixed ankle versus hydraulic ankle were examined.

Method

Components: Transtibial 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 transtibial (TT) amputees (18 male, 3 female, mean age 48.2 ± 12.8 years, height 1.78 ± 0.07 m, mass 87.4 ± 13.2 kg).

Data collection protocol: Prosthetic intervention and exchange of the habF with hyA-F after period of acclimatization, 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 intact 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 intact 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.

Related Products:

Echelon, Elan, EchelonVT

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[4], 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 transtibial and transfemoral amputees. The effect of ankle foot mechanism on gait progression characteristics was determined.

Method

Components: Transtibial and transfemoral 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: 19 lower limb amputees (8 transfemoral (mean age 42 years, mass 86.3kg), 11 transtibial (mean age 47 years, mass 84.5kg), K3 activity level.

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 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.

Conclusion

The authors conclude that MTC is increased with use of a hydraulic ankle, and that this may reduce the risk factor for falling. 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.

Related Products:

Echelon, Elan, EchelonVT

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

Published in: 1st Clinical Movement Analysis World Conference, 23rd Annual Meeting of the European Society for Movement Analysis in Adults and Children (ESMAC), Rome 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”), and a hydraulic ankle feet (Echelon “EC” and 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: 1 unilateral transfemoral 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 (Elan), with ES (esprit) producing the largest joint moments in every test condition. On the intact limb the knee joint moments 6-78% higher when using ES (esprit) compared to the Elan. The intact hip extension moments were lowest in every condition using EL (Elan). On the residual hip extension moments were 10 times larger with ES (esprit) compared to EL (Elan). The residual hip flexion moments using ES (esprit) were 40% larger compared to EL (Elan).

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 transfemoral amputees when walking on graded inclines.

Related Products:

Echelon, Elan, EchelonVT

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[4], 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: Transtibial 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 transtibial amputees (K3), mean, age 44.8, mass 83.3kg, height 1.77m.

Data collection protocol: Prosthetic intervention and exchange of the habF with hyA-F after period of acclimatization, 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 intact-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 intact-limb, ankle and combined joints work per metre travelled were significantly lower (0.77 vs 0.92 J/kgm/s, 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 intact-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.

Related Products:

Echelon, Elan, EchelonVT

Kinematics, kinetics and internal mechanical stresses of transtibial 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[4], I. Siev-Ner[1]

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

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

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

Published in: Orthopädie + Reha-Technik 2012

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 habitual non hydraulic foot and ankle.

Measurements: Kinematics and kinetics, opto-electronic motion capture (CODA-3D), 4 force plates. In socket pressure measurement system.

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

Data collection protocol: 2 test session, (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.

Related Products:

Echelon, Elan, EchelonVT

Einfluss der Eigenschaften eines Prothesenfusses auf das Gangbild von Unterschenkel-Amputierten – Influence of the characteristics of a prosthetic foot on the gait of transtibial 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 transtibial 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: Foot of patient and test foot (Echelon, Endolite)

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

Subjects: 13 transtibial amputees, 48.7±11.8 years, 2 female and 11 male, mobility level K2-K4 and no comorbidities that influence gait.

Data collection protocol: All investigations were undertaken with the own foot of the subject and the test foot (Echelon, Endolite). 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. Questionnaire evaluation.

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. Plantarflexor 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.

Related Products:

Echelon, Elan, EchelonVT

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

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

[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 (42-62 years), 3 unilateral transtibial, 3 transfemoral, 3 bilateral transtibial.

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%), ‘prosthesis satisfaction’ (+19.6%) and ‘gait satisfaction’ (+25.3%), all $p<0.01$. The largest magnitude of improvement was reported by the bilateral amputee group with a 33.4% improvement in gait satisfaction.

Conclusion

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

Related Products:

Echelon, Elan, EchelonVT

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 roll-over 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: 20 physical active amputees' transtibial amputees (aged 47.4 ±12 years, mass 87.3±13.5kg, and height 1.79±0.06m).

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.

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.

Related Products:

Echelon, Elan, EchelonVT

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 Center, 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: n=9 male unilateral traumatic trans-tibial amputees, with 6 to 36 post amputation and a mean age of 42.7 year.

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: 5 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.

Related Products:

Echelon, Elan, EchelonVT

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

Published in: 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: 20 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.

Related Products:

Echelon, Elan, EchelonVT

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] Disablement of Biomedical Engineering, Tel Aviv University, Ramat Aviv, 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 transtibial 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: 9 active, male unilateral trans-tibial amputees (age 42 ± 12 years, weight 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 users 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.

Related Products:

Echelon, Elan, EchelonVT

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] Disablement of Biomedical Engineering, Tel Aviv University, Ramat Aviv, Israel

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

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

Published in: Proceeding 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: 10 active, unilateral trans-tibial amputees (age 43 ± 12 years, weight 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 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.

Related Products:

Echelon, Elan, EchelonVT

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

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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 (TT) and trans-femoral (TF) 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: 10 physically active amputees (6 TT, 4TF, mean age 43.9 ± 13.1 years, height 1.77 ± 0.07m, mass 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 was 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.

Related Products:

Echelon, Elan, EchelonVT

*Non statistical difference

Roll-over characteristics and ankle joint kinetics using low-profile dynamicresponse 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. 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

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

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Summary

This study reports on gait analysis including roll-over shape analysis conducted to investigate changes in amputee gait when using the 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 transtibial amputees (age 37.3 ± 3.3 years, mass 74.8± 10 kg, height 1.74±0.04m).

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 plantar-flexion 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 CoM being transferred onto the prosthetic limb in a smoother manner.

Related Products:

Echelon, Elan, EchelonVT