UNIVERSITY OF TORONTO LIBRARIES

CPOJ

ISSN: 2561-987X

LITERATURE REVIEW

Canadian Prosthetics & Orthotics Journal

CPOJ Website: https://jps.library.utoronto.ca/index.php/cpoj/index
Editorial Office: cpoj@online-publication.com
ISSN 2561-987X

VOLUME 1, ISSUE 1

2 0 1 8

LITERATURE REVIEW

EVIDENCE ON PROSTHETIC FEET WITH ACTIVE DORSIFLEXION FEATURE, PASSIVE MICROPROCESSOR CONTROL AND ACTIVE ANKLE POWER GENERATION: A MINI LITERATURE REVIEW.

Andreas Kannenberg*

Executive Medical Director North America, Department of Medical Affairs, Otto Bock HealthCare, Austin, TX, USA.

ABSTRACT

This paper reviewed 11 publications on non-MP controlled ankles with active dorsiflexion feature, 15 publications on passive MP controlled ankles, and 12 publications on powered MP controlled ankle-foot mechanisms. Methodological quality of publications was low to moderate. The evidence found was mostly biomechanical and generated in gait lab studies. Non-MP ankles may increase toe clearance and reduce braking forces during level walking, thus supporting propulsion with increase in walking speed. Passive MP controlled ankles may also increase toe clearance and reduce the likelihood of stumbling over an unseen obstacle. They may reduce energy expenditure during level walking and facilitate slope and stair ambulation. Non-MP and passive MP controlled ankles have been also been shown to reduce residual limb-socket interface pressures. Powered ankles may increase walking speed to the level of and decrease energy expenditure to be no longer significantly different from that of able-bodied individuals. Also, at higher walking speeds the sound knee loading may be reduced by up to 15-20%. However, it remains unclear to what extent the gait lab results for all advanced ankle-foot mechanisms can be transferred to real-life benefits in the free-living environment.

ARTICLE INFO

Received: July 23, 2018
Accepted: August 29, 2018
Published: September 1, 2018

CITATION

Kannenberg A. Evidence On Prosthetic Feet With Active Dorsiflexion Feature, Passive Microprocessor Control And Active Ankle Power Generation: A Mini Literature Review. Canadian Prosthetics & Orthotics Journal, Volume 1, Issue 1, No. 6, 2018. DOI: https://doi.org/10.33137/cpoj.v1i1.30450

KEYWORDS

Prosthetic Feet, Microprocessor Control, Active Ankle Power, Active Dorsiflexion, Powered ankles, Passive Microprocessor, Medline, Rehabilitation, Prosthetics.

INTRODUCTION

Microprocessor technology has been adopted in prosthetic knees for almost 30 years and in prosthetic feet for about 10 years. Several systematic reviews of the literature on microprocessor-controlled knees have confirmed their benefits in safety and mobility, supporting their use in individuals with transfemoral amputation and MFCL-3 and also MFCL-2 mobility. However, microprocessor-controlled (MP) passive and powered feet are widely considered experimental, investigational and unproven by health insurances.

METHOD

The Medline and EMBASE databases as well as the online library of the Journal of Prosthetics and Orthotics were searched on January 15, 2018, for publications using search terms related to feet with non-MP hydraulic ankles/dorsiflexion feature, or passive or powered microprocessor controlled feet.

*CORRESPONDING AUTHOR:
Dr. Andreas Kannenberg, Executive Medical Director North America, Department of Medical Affairs, Otto Bock HealthCare, Austin, TX, USA.
Email: andreas.kannenberg@ottobock.com
DOI: https://doi.org/10.33137/cpoj.v1i1.30450

The search terms were combined into a title, abstract, and key word search phrase using Boolean operators, resulting in the following syntax: amput* OR prosth* AND foot OR ankle OR hydraulic OR dorsiflexion OR linkage OR microprocessor OR MP* OR power*. The literature search was repeated on June 30, 2018, to identify recent publications since the original search date. Titles and abstracts of the identified publications were screened for their scope.

Technical papers and case studies were excluded. Publications on biomechanical and clinical studies were rated for methodological quality using the criteria of a Cochrane review of prosthetic foot research by Hofstad et al.[1] Publications with good enough methodological quality were reviewed in full and results were extracted and summarized.

RESULTS

The literature search yielded 12 publications (reference 2-13) on biomechanical and/or clinical studies with a prosthetic foot with a non-MP controlled hydraulic ankle/dorsiflexion feature, 16 publications (reference 14-29) on passive and 17 publications (reference 30-46) on powered MP controlled prosthetic ankle-foot mechanisms. One publication on non-MP feet (12), one publication on passive MP feet (14) and 5 publications on powered ankle-foot mechanisms (35, 40, 44-46) were excluded from the review for insufficient methodological quality.

All included studies had low to moderate methodological quality and all but one were conducted with individuals with unilateral transtibial amputations. Compared to standard energy storage and return (ESAR) feet, the studies with a foot with a non-MP hydraulic ankle/dorsiflexion feature demonstrated a significantly increased toe clearance and self-selected walking speed on level ground. In addition, studies reported reduced braking forces (improved progression of the center of pressure under the foot), smoother gait and reduced perception of having to “climb over the prosthetic limb” by the patients. One study demonstrated reduced interface pressures between the socket and residual limb while walking on level and uneven terrain and ascending and descending slopes and stairs.

One study with a passive MP controlled prosthetic foot also demonstrated significantly improved toe clearance during over-ground walking, reducing the likelihood of tripping over an unseen obstacle of 0.5 cm height from 1/166 steps with an ESAR foot to 1/3,169 steps with the MP foot. Studies also found a reduction of metabolic energy consumption on level ground and a reduction in perceived energy demand for walking up slopes. One study found some improvements but also some deteriorations in biomechanical parameters during slope ambulation. Another study demonstrated that it was easier with a MP controlled than with a non-MP controlled hydraulic ankle to control the walking speed while descending a 5° slope. One study with a MP controlled foot with instant terrain adaption and a dorsiflexion stop found that it was more physiologic to stand on a 10° incline and decline with this foot than with other MP controlled feet with only gradual terrain adaption and no dorsiflexion stop. One study found some improvements in biomechanical parameters while ascending and descending stairs. Finally, one study also demonstrated significantly reduced interface stress between the socket and the residual limb when using a MP controlled foot as compared to a standard ESAR foot on varying terrains.

Studies with a MP controlled powered ankle-foot component found that subjects able to walk with at least 1.2 m/s with their regular ESAR foot have a good chance to further increase their self-selected walking speed to the level of able-bodied individuals. At higher walking speeds of 1.5 to 1.75 m/s, use of a powered foot may result in a significant 15-20% reduction of sound knee loading, which may have the potential to reduce incidence rates of sound knee osteoarthritis related to long-term prosthesis use.

Studies also found improved stability while walking on level ground and slopes. There is conflicting evidence on the reduction in metabolic energy consumption during over ground walking: One study showed a significant decrease in energy expenditure, whereas another study could only confirm that for subjects with MFCL-4 mobility. Finally, studies reported significantly improved push-off and walking speed on uneven terrain and normalized ankle power generation and increased plantarflexion during stair ascend.

DISCUSSION

A total of 38 publications on the benefits of prosthetic feet with non-MP hydraulic ankles/dorsiflexion feature, passive or powered MP controlled ankles was reviewed. Most of the studies had been conducted in gait labs and focused on biomechanical parameters of gait.

Clinically, the most relevant finding was that non-MP and passive MP controlled ankles may have the potential to increase toe clearance and, thus, reduce the risk of tripping. However, it remains to be studied if that feature also results in reduced falls in the free-living environment. Improved passive ankle motion may result in reduced braking forces, increased self-selected walking speed, and reduced interface pressures between the residual limb and the socket on varying terrains.

Passive MP controlled feet may also improve the ability to navigate slopes and stairs. Powered feet may enable high-functioning individuals with transtibial amputation to further increase their self-selected walking speed to the level of able-bodied subjects while significantly reducing sound knee loading at higher walking speeds. Some subjects may also benefit from using a powered ankle-foot component by reducing metabolic energy consumption at faster walking speeds. However, none of studies reported any criteria for identifying patient groups who are more likely to benefit from either type of advanced foot technology than others. Thus, matching the right patient with the individually best advanced prosthetic ankle-foot mechanism remains a difficult challenge to clinicians.

CONCLUSION

Prosthetic feet with non-MP or passive MP controlled hydraulic ankles/dorsiflexion feature may be considered for transtibial amputees with compromised toe clearance and tendency to trip. These feet may also be considered for patients who experience increased residual stress while negotiating uneven terrain, slopes and stairs. Powered prosthetic feet may be considered for high-functioning individuals with transtibial amputations who want to further increase their walking capabilities and reduce their long-term risk of developing sound knee osteoarthritis.

REFERENCES

1. Hofstad CJ, van der Linde H, van Limbeek J, Postema K. Prescription of prosthetic ankle-foot mechanisms after lower limb amputation. Cochrane Database of Systematic Reviews. Cochrane database of systematic reviews (Online) 4(1):CD003978, DOI: 10.1002/14651858.CD003978.pub2.

A. References for non-MP feet/ankle with ankle ROM and dorsiflexion feature (2-13)

2. Heitzmann DWW, Salami F, DeAsha DR, Block J, Putz C, Wolf SI, Alimusaj M. Benefits of an increased prosthetic ankle range of motion for individuals with transtibial amputation walking with a new prosthetic foot. Gait Posture 2018;64:174-180. DOI: 10.1016/j.gaitpost.2018.06.022.

3. Childers LW, Takahashi KZ. Increasing foot energy return affects whole-body mechanics during walking on level ground and slopes. Nature Scient Reports 2018;8:5354. DOI:10.10138/s441598-0118-23705-8.

4. Bai X, Ewins D, Crocombe AD, Wei X. Kinematic and biomimetic assessment of a hydraulic ankle/foot in level ground and camber walking. PLoS One. DOI:10.1371/journal.pone.0180836 July 13, 2017.

5. Koehler-McNicholas SR, Nickel EA, Medvec J, Barrons K, Mion S, Hansen AH. The influence of a hydraulic prosthetic ankle on residual limb loading during sloped walking. PLoS One. DOI:10.1371/journal.pone.0173423 March 9, 2017.

6. Moore R. Patient evaluation of a novel prosthetic foot with hydraulic ankle aimed at persons with amputation with lower activity levels. J Prosthet Orthot. 2017;29(1):44-47. DOI: 10.1097/JPO. 0000000000000120.

7. Moore R. Effect on stance phase timing asymmetry in individuals with amputation using hydraulic ankle units. J Prosthet Orthot. 2016;28(1):44-48. DOI: 10.1097/JPO.0000000000000083.

8. De Asha AR, Munjal R, Kulkarni J, Buckley JG. Impact on the biomechanics of overground gait using an 'Echelon' hydraulic ankle-foot device in unilateral trans-tibial and trans-femoral amputees. Clin Biomech. 2014; 29: 728-734. DOI.org/10.1016/j.clinbiomech.2014.06.009.

9. Johnson L, De Asha AR, Munjal R, Kulkarni J, Buckley JG. Toe clearance when walking in people with unilateral amputation: Effects of passive hydraulic ankle. J Rehabil Res Dev. 2014; 51(3): 429-438. DOI: 10.1682/JRRD.2013.05.0126.

10. 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. DOI:10.1016/j.clinbiomech.2012.11.013.

11. 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 Neuroeng Rehabil. 2013; 10: 107-121. DOI.org/10.1186/1743-0003-10-107.

12. Sedki I, Moore R. Patient evaluation of the Echelon foot using the Seattle Prosthesis Evaluation Questionnaire. Prosthet Orthot Int. 2013; 37: 250-254, DOI: 10.1177/0309364612458448.

13. 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 feet. Gait Posture. 2012; 35: 121-125. DOI: 10.1016/j.gaitpost.2011.08.021.

B. References for passive MP-controlled feet/ankle (14-29)

14. Schmalz T, Altenburg B, Ernst M, Bellmann M, Rosenbaum D. O 010 – Ramp walking with abruptly changing inclines: Motion pattern of TT amputees fitted with a microprocessor-controlled and a conventional prosthetic foot. Gait Posture. 2018. DOI: 10.1016/j.gaitpost.2018.06.019.

15. Ernst M, Altenburg B, Bellmann M, Schmalz T. Standing on slopes – how current microprocessor-controlled prosthetic feet support transtibial and transfemoral amputees in everyday tasks. J NeuroEngin Rehabil. 2017; 16;14(1):117. DOI: 10.1186/s12984-017-0322-2.

16. Hahn A, Sreckovic I, Reiter S, Mileusnic M. Fist results concerning the safety, walking and satisfaction with an innovative, microprocessor-controlled four axes prosthetic foot. Prosthet Orthot Int. 2018; 42(3):350-356. DOI: 10.1177/0309364617747976.

17. Alexander N, Strutzenberger G, Kroell J, Barnett CT, Schwameder H. Joint moments during downhill and uphill walking of a person with transfemoral amputation with a hydraulic articulating and a rigid prosthetic ankle – a case study. J Prosthet Orthot. 2018;30:46-54. DOI:10.1097/JPO.0000000000000171.

18. 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. DOI:10.1016/j.clinbiomech.2015. 11.015.

19. Rosenblatt NJ, Bauer A, Rotter D, Grabiner MD. Active dorsiflexing prostheses may reduce trip-related fall risk in people with transtibial amputation. J Rehabil Res Dev. 2014; 51(8): 1229-1242. DOI: 10.1682/JRRD.2014.01.0031.

20. Darter BJ, Wilken JM. Energetic consequences of using a prosthesis with adaptive ankle motion during slope walking in persons with a transtibial amputation. Prosthet Orthot Int. 2014; 38(1):5-11. DOI: 10.1177/0309364613481489.

21. Agrawal V, Gailey R, O´Toole C, Gaunard I, Finnieston A, Tolchin R. Comparison of four different categories of prosthetic feet during ramp ambulation in unilateral transtibial amputees. Prosthet Orthot Int. 2015;39(5):380-9. DOI: 10.1177/0309364614536762.

22. Agrawal V, Gailey R, O´Toole C, Gaunard I, Finnieston A. Influence of gait training and prosthetic foot category on external work symmetry during unilateral transtibial gait. Prosthet Orthot Int. 2013; 37(5): 396-403. DOI: 10.1177/0309364612473501.

23. Agrawal V, Gailey R, O´Toole C, Gaunard I, Finnieston A. Comparison between microprocessor-controlled ankle/foot and conventional prosthetic feet during stair negotiation in people with unilateral transtibial amputation. J Rehabil Res Dev. 2013; 50(7): 941-950. DOI: 10.1682/JRRD.2012.05.0093.

24. Delussu AS, Brunelli S, Paradisi F, Iosa M, Pellegrini R, Zenardi D, Traballesi M. Asessment of the effects of carbon fiber and bionic foot during overground and treadmill walking in transtibial amputees. Gait Posture. 2013; 38: 876-882. DOI: 10.1016/j.gaitpost.2013.04.009.

25. Gailey RS, Gaunard I, Agrawal V, Finnieston A, O´Toole C, Tolchin R: Application of self-report and performance-based outcome measures to determine functional differences between four categories of prosthetic feet. J Rehabil Res Dev. 2012;49(4):597-612.

26. Fradet L, Alimusaj M, Braatz F, Wolf SI. Biomechanical analysis of ramp ambulation of transtibial amputees with an adaptive ankle system. Gait Posture. 2010; 32: 191-198. DOI: 10.1016/j.gaitpost.2010.04.011.

27. Agrawal V, Gailey R, O´Toole C, Gaunard I, Dowell T. Symmetry in External Work (SEW): A novel method of quantifiying gait differences between prosthetic feet. Prosthet Orthot Int. 2009; 33(2): 148-156. DOI: 10.1080/03093640902777254.

28. Alimusaj M, Fradet L, Braatz F, Gerner HJ, Wolf SJ. Kinematics and kinetics with an adaptive ankle foot system during stair ambulation of transtibial amputees. Gait

Posture. 2009; 30: 356-363. DOI: 10.1016/j.gaitpost.2009.06.009.

29. Wolf SI, Alimusaj M, Fradet L, Siegel J, Braatz F. Pressure characteristics at the stump/socket interface in transtibial amputees using an adaptive prosthetic foot. Gait Posture. 2009; 24: 860-865. DOI: 10.1016/j.clinbiomech.2009.08.007.

C. References for powered feet/ankle (30-46)

30. Gardinier ES, Kelly BM, Wensmen J, Gates DH. A controlled clinical trial of a clinically-tuned powered ankle prosthesis in people with transtibial amputation. Clin Rehabil. 2018; 32(3):319-329. DOI: 10.1177/0269215517723054.

31. Pickle NT, Grabowski AM, Jeffers JR, Silverman AK. The functional roles of muscles, passive prostheses, and powered prostheses during sloped walking in people with transtibial amputation. J Biomech Eng. 2017;1;139(11). DOI: 10.1115/1.4037938.

32. Rabago CA, Aldridge Whitehead J, Wilken JM. Evaluation of a powered ankle-foot prosthesis during slope ascent gait. PLoS One. 15;11(12):e0166815. DOI: 10.1371/journal.pone.0166815. eCollection 2016.

33. Pickle NT, Wilken JM, Aldridge Whitehead JM, Silverman AK. Whole-body angular momentum during sloped walking using passive and powered lower-limb prostheses. J Biomech. 2016 3;49(14):3397-3406. DOI:10.1016/j.jbiomech.2016.09.010.

34. Russell Esposito E, Aldridge JM, Wilken JM. Step-to-step transition work during level and inclined walking using passive and powered ankle-foot prostheses. Prosthet Orthot Int. 2016;40(3):311-9. DOI: 10.1177/0309364614564021.

35. Takahashi KZ, Horne JR, Stanhope SJ. Comparison of mechanical energy profiles of passive and active below-knee prostheses: A case study. Prosthet Orthot Int. 2015;39(2):150-6. DOI: 10.1177/0309364613513298.

36. D'Andrea S, Wilhelm N, Silverman AK, Grabowksi AM. Does use of a powered ankle-foot prosthesis restore whole-body angular momentum during walking at different speeds? Clin Orthoped Rel Res. 2014;472:3044-3054. DOI 10.1007/s.11999-014-3647-1.

37. Russell Esposito E, Wilken JM. Biomechanical risk factors for knee osteoarthritis when using passive and powered ankle-foot prostheses. Clin Biomech. 2014;29(10):1186-92. DOI:10.1016/j.clinbiomech.2014.09.005.

38. Grabowski AM, D'Andrea S. Effects of a powered ankle-foot prosthesis on kinetic loading of the unaffected leg during level-ground walking. J NeuroEng Rehabil. 2013; 7;10:49. DOI: 10.1186/1743-0003-10-49.

39. Gates DH, Aldridge JM, Wilken JM. Kinematic comparison of walking on uneven ground using powered and unpowered prostheses. Clin Biomech. 2013;28(4):467-72. DOI:10.1016/j.clinbiomech.2013.03.005.

40. Hill D, Herr H. Effects of a powered ankle-foot prosthesis on kinetic loading of the contralateral limb: A case series. IEEE Int Conf Rehabil Robot. 2013 ;2013:6650375. DOI: 10.1109/ICORR.2013.6650375.

41. Herr HM, Grabowski AM. Bionic ankle-foot prosthesis normalizes walking gait in for persons with leg amputations. Proc R Sco B 2012; 7;279(1728):457-64. DOI: 10.1098/rspb.2011.1194.

42. Ferris AE, Aldridge JM, Rabago C, Wilken JM. Evaluation of a powered ankle-foot system during walking. Arch Phys Med Rehabil. 2012 ;93(11):1911-8. DOI: 10.1016/j.apmr.2012.06.009.

43. Aldridge JM, Sturdy JT, Wilken JM. Stair ascent kinematics and kinetics with a powered lower leg system following transtibial amputation. Gait Posture. 2012;36:291-295. DOI 10116/j.gaitpost.2012.03.013.

44. Mancinella C, Patritti BL, Tropea P, Greenwald RM, Casler R, Herr H, Bonato P. Comparing a passive-elastic and a powered prosthesis in transtibial amputees. Conf Proc IEEE Eng Med Biol Soc. 2011;2011:8255-8. DOI: 10.1109/IEMBS.2011. 6092035.

45. Au SK, Weber J, Herr H. Powered ankle-foot prosthesis improves walking metabolic economy. IEEE Transactions Robotics. 2009;25(1):51-66. DOI: 10.1109/TRO.2008.2008747.

46. Au SK, Herr H, Weber J, Martinez-Villalpando EC. Powered ankle-foot prosthesis for the improvement of amputee ambulation. Conf Proc IEEE Eng Med Biol Soc. 2007;2007:3020-6.

DISCLOSURE

Dr. Andreas Kannenberg is a full-time employee of Otto Bock HealthCare LP, Austin, TX.