Evidence Note | Outcomes Associated with the Use of Microprocessor- and Non-Microprocessor-Controlled Prosthetic Knees after Unilateral Transfemoral Limb Loss

Key Points

- At this time, there is evidence to suggest that microprocessor-controlled prosthetic knees (MPKs) provide greater ambulatory safety and improve environmental obstacle negotiation when compared to non-microprocessor-controlled prosthetic knees (NMPKs) among individuals with unilateral transfemoral limb loss.
- There is also some evidence to suggest that MPKs provide improvements in patient-reported activity, cognitive demand, quality of life, preference, and satisfaction. Similar evidence suggests that although the initial acquisition cost associated with MPKs is greater than that for NMPKs, the total costs of prosthetic rehabilitation are similar between MPKs and NMPKs. There is limited evidence to suggest MPKs reduce metabolic energy expenditure and improve gait mechanics. No evidence was found to indicate that NMPKs improve clinical outcomes when compared to MPKs.
- Additional quality research is required to confirm and expand upon the currently available evidence for the prescription and use of MPKs.

Scope of Review

The purpose of this Evidence Note is to provide a summary of the outcomes related to the use of microprocessor-controlled prosthetic knees (MPKs) compared to non-microprocessor-controlled prosthetic knees (NMPKs) among individuals with unilateral transfemoral limb loss. This synopsis of the existing empirical evidence is intended to complement other sources of available knowledge,[1] such as experiential evidence, physiological rationale, and patient values and goals, in order to facilitate an evidence-based approach to the prescription of MPKs and NMPKs. Peer-reviewed publications that compared the use of any type of MPK to any type of NMPK among individuals with unilateral transfemoral or knee disarticulation limb loss contributed to the development of this Evidence Note.

Etiology and Functional Limitations

There are currently more than 1.6 million individuals with limb loss in the United States.[2] Of these cases, more than 600,000 are considered major amputations (the loss of a limb other than the toes).[2] Based upon the reported incidence of transfemoral limb loss (TFLL) in this population,[3] an estimated 160,000 cases of TFLL are now present in the United States. Limb loss greatly impacts overall health, functional activities, and involvement in life situations. For example, TFLL is associated with secondary disabilities,[4–8] lower return-to-work rates,[9] decreased capacity for ambulation,[10–13] reduced safety,[14–16] and decreased quality of life.[17,18]

Description and History of Microprocessor-Controlled Prosthetic Knees

The selection of an appropriate prosthetic knee is considered to be fundamental to a successful outcome for individuals with TFLL.[19] Currently, more than 220 different prosthetic knees are available to the clinical prosthetist.[20] Among these are models that incorporate a microprocessor control system.[21] MPKs acquire and use position, load, and velocity information to regulate the knee's resistance to flexion and/or extension during the swing and/or stance phases of gait. MPKs have been commercially available since 1990 although developmental efforts related to electronic control of prosthetic knees date back to the 1970s.[22,23] Initial commercial designs focused on microprocessor control during swing phase (swing-only MPK), while more recent models have incorporated microprocessor stance-phase control (stance-only MPK or swing-and-stance MPK). In all cases, integration of the microprocessor control system into the prosthetic knee unit is aimed at addressing functional limitations experienced by the user.

Summary of Evidence

The findings presented in this Evidence Note were derived from a systematic evaluation of 27 peer-reviewed publications published between 1996 and 2009. These publications were identified through a subject-specific search of several common healthcare and biomedicine databases, including PUBMED, CINHAL, RECAL Legacy, and the Cochrane Library.

Outcomes comparing MPKs to NMPKs among individuals with unilateral TFLL were extracted from the 27 reviewed publications and grouped into nine topic areas. These included environmental obstacle negotiation, ambulatory safety, activity, cognitive demand while walking, quality of life, economics, patient preference and satisfaction, metabolic energy expenditure, and gait mechanics. Outcomes related to each topic area and the strength of the evidence (high, moderate, low, or insufficient) associated with these outcomes were examined by the Evidence Note authors. The strength of the evidence assigned to the reviewed outcomes was based upon three principles: *quality,* the methodological quality of the individual studies that contributed to the findings; *quantity,* the number of studies that contributed to the findings; and *consistency,* the extent to which the reported findings were in agreement.

There are multiple outcomes that indicate the potential for MPKs to improve *environmental obstacle negotiation* and enhance *ambulatory safety.* There is moderate evidence that swing and stance MPKs increase self-selected walking speed on uneven terrain[24–27] and improve gait patterns during stair descent.[24–26] There is preliminary, but not yet substantiated, evidence to indicate that they improve gait patterns during hill descent.[24,25] There is moderate evidence that the number of reported falls is decreased[24–26,28] and that patient confidence is increased[24,25,29,30] when using swing and stance MPKs as compared to NMPKs. Initial evidence also suggests that MPKs decrease reported frustration with falling, but further research is needed to confirm this finding.[24,25] These *environmental obstacle negotiation* and *ambulatory safety* outcomes appear to be related to the stability features offered by swing and stance MPKs. This is notable, as MPKs are traditionally classified as fluid-controlled knees and therefore prescription criteria generally pertain to features of mobility (such as variable cadence). The findings reported in the literature suggest that indications for MPKs that offer microprocessor stance control should also include individuals who might require the inherent stability provided by these knees.

Outcomes related to *activity* and *cognitive demand while walking* appear to vary by the method used to measure the outcome. For example, there is moderate evidence to suggest that swing and stance MPKs increase self-reported mobility,[24–26,31–34] but do not change the amount of activity performed.[25,35] This may indicate a potential change in type of activity or ease with which it is performed rather than the quantity of activity (number of steps) performed. Similarly, there is moderate evidence to suggest that patient-reported *cognitive demand while walking* is reduced with the use of swing and stance MPKs,[24,25,36] although this perceived difference has not been confirmed through quantitative measurement of cognitive burden.[24,25 36,37] For both *activity* and *cognitive demand,* the reported disparity between patient-reported and physiologically measured outcomes may be related to the selected instruments' sensitivity (the ability to detect change) to those differences noted by subjects. This finding could also be attributed to a placebo effect, as neither study subjects nor investigators are typically blinded to the interventions in these studies.

There is moderate evidence to indicate that swing and stance MPKs improve *quality of life,* as defined by patient-reported well-being,[24,25,33] but that they do not change self-reported general health.[25,34] This finding is likely due to the focus of the instrument used to assess each outcome. Those studies that assessed well-being did so with a population-specific instrument, the Prosthesis Evaluation Questionnaire (PEQ), designed for use with individuals with lower-limb loss.[38] Those that assessed general health used a generic instrument (the Short Form 36 or SF-36).[39] The questions included in the PEQ call specific attention to use of the prosthesis, while SF-36 questions are directed at sickness and health. Thus, the SF-36 may not be as sensitive to changes resulting from a prosthetic intervention (like an MPK) as would the PEQ.

There is moderate and low evidence to suggest that the prescription and use of swing and stance MPKs is associated with greater *patient preference*[25,26,28,40] and *satisfaction,*[3,25,26] respectively. There is also low evidence to suggest that swing-only MPKs are associated with increased *patient preference* compared to NMPKs.[31,41] Interestingly, preference was not always associated with performance. In one study, performance-related outcomes were noted to improve with use of the MPK, yet certain subjects still preferred the NMPK.[26] This raises interesting questions regarding optimal user candidacy and prescription criteria for MPKs and indicates that further investigation is warranted so as to better understand the social, physical, and psychological characteristics associated with prosthetic knee use.

Economic outcomes have been used to assess the relative costs associated with the different prosthetic knee interventions. Despite significantly higher acquisition costs associated with MPK interventions,[32,34,42] there is moderate evidence to suggest that overall costs of prosthetic rehabilitation (from a societal perspective) are equivalent between swing and stance MPKs and NMPKs.[32,34] Overall costs in this context include not only the original acquisition costs, but also other long-term costs such as the loss of productivity, home adaptations, and housekeeping assistance.

There is limited evidence to suggest that the use of MPKs affects change in *metabolic energy expenditure* or *gait mechanics* when compared to the use of NMPKs among individuals with unilateral TFLL. There is low evidence to suggest that swing and stance MPKs decrease oxygen (O_2) rate at self-selected walking speed (SSWS)[27,43,44] and that swing-only MPKs do not change O_2 rate across a range of walking speeds.[41,45,46] There is moderate evidence to suggest that swing and stance MPKs and NMPKs require similar O_2 costs across a range of walking speeds.[27,33,40] Oxygen cost is generally a preferred measure of *metabolic energy expenditure* as it accounts for changes in walking speed, while O_2 rate does not. This is important as individuals with TFLL are reported to adjust walking speed to maintain an O_2 rate that is equivalent to that of ambulating, able-bodied individuals.[47] Therefore, O_2 rate alone may not adequately explain the change in metabolic energy expenditure induced by the intervention.

Although well researched, few changes to *gait mechanics* outcomes were associated with different types of prosthetic knees. There is low evidence to suggest that swing and stance MPKs increase SSWS.[26,40,43,48] However, moderate evidence indicates that SSWS is not influenced by swing-only MPKs.[41,49] Spatial gait asymmetry appears to be unaffected by either swing and stance MPKs,[25,28,48] or swing-only MPKs[41,49] based upon moderate and low evidence, respectively. Mixed findings related to temporal gait symmetry,[28,43] peak prosthetic stance-phase knee flexion angle in early stance,[48,50,51] and prosthetic side hip power in late stance[43,48] suggest that these outcomes are equivalent between swing and stance MPKs and NMPKs. Finally, an increased prosthetic knee moment in early stance phase with the use of swing and stance MPKs is supported by low evidence.[43,48,51] It is worth noting that these *gait mechanics* outcomes were obtained in controlled laboratory environments that may not represent individuals' free-living environments.

A number of methodological issues were identified upon review of this body of literature. Many of these issues were not addressed by the publications' authors, which limited the overall strength of evidence reported in this Evidence Note. Those that were identified and perceived to be relevant to the outcomes presented include selecting a suitable control/comparison condition, defining appropriate inclusion/exclusion criteria for study subjects, blinding subjects and/or researchers to the intervention, addressing fatigue and/or learning effects during subject testing, explaining and/or addressing subject attrition over the study period, recruiting an appropriate sample size, defining meaningful changes in measured outcomes, and recruiting subjects representative of a targeted population. Many of these issues pertain as much to the description of the studies (the publications) as to the studies themselves, and may be easily addressed in the future.

Future Research

As indicated by the lack of "high" evidence, additional research with strong methodological quality is required to confirm, build upon, and expand the currently available evidence for the prescription and use of MPKs. Areas of future interest may include, but are not limited to, differences between Medicare Functional Classification Levels, time to acclimation with a new component, testing in free-living environments, and the role of technology versus therapy. The importance of these (and related) issues will continue to grow as advanced technology, like microprocessor control, becomes more common in prosthetic and orthotic solutions.

Acknowledgments

This Evidence Note was compiled by Brian J. Hafner, PhD, and made possible by the American Academy of Orthotists and Prosthetists (the Academy) through a grant (Award Number H235K080004) from the U.S. Department of Education. The contents do not necessarily represent the policy of the Department of Education, and endorsement by the federal government should not be assumed.

Suggested Citation

Hafner B. Evidence Note: Outcomes Associated with the Use of Microprocessor- and Non-Microprocessor-Controlled Prosthetic Knees after Unilateral Transfemoral Limb Loss. Washington DC: American Academy of Orthotists and Prosthetists. (2011)

References

1. Tonelli MR. Integrating evidence into clinical practice: an alternative to evidence-based approaches. *J Eval Clin Pract.* 2006;12(3):248–256.
2. Ziegler-Graham K, MacKenzie EJ, Ephraim PL, Travison TG, Brookmeyer R. Estimating the prevalence of limb loss in the United States: 2005 to 2050. *Arch Phys Med Rehabil.* Mar 2008;89(3):422–429.
3. Dillingham T, Pezzin L, MacKenzie EJ. Limb amputation and limb deficiency: epidemiology and recent trends in the United States. *South Med J.* 2002;95:875–883.
4. Hungerford DS, Cockin J. Fate of the retained lower limb joints in Second World War amputees. Proceedings and Reports of Universities, Colleges, Councils, and Associations. *J Bone Joint Surg Br.* 1975;57(111).
5. Kulkarni J, Adams J, Thomas E, Silman A. Association between amputation, arthritis and osteopenia in British male war veterans with major lower limb amputations. *Clin Rehabil.* 1998;12(4):348–353.
6. Mussman M, Altwerger W, Eisenstein J, Turturro A, Glockenberg A, Bubbers L. Contralateral lower extremity evaluation with a lower limb prosthesis. *J Am Podiatry Assoc.* 1983;73(7):344–346.
7. Norvell DC, Czerniecki JM, Reiber GE, Maynard C, Pecoraro JA, Weiss NS. The prevalence of knee pain and symptomatic knee osteoarthritis among veteran traumatic amputees and nonamputees. *Arch Phys Med Rehabil.* 2005;86(3):487–493.
8. Robbins CB, Vreeman DJ, Sothmann MS, Wilson SL, Oldridge NB. A review of the long-term health outcomes associated with war-related amputation. *Mil Med.* 2009;174(6):588–592.
9. Hebert JS, Ashworth NL. Predictors of return to work following traumatic work-related lower extremity amputation. *Disabil Rehabil.* 2006;28(10):613–618.
10. Davies B, Datta D. Mobility outcome following unilateral lower limb amputation. *Prosthet Orthot Int.* 2003;27(3):186–190.
11. Holden JM, Fernie GR. Extent of artificial limb use following rehabilitation. *J Orthop Res.* 1987;5(4):562–568.
12. Waters RL, Mulroy S. The energy expenditure of normal and pathologic gait. *Gait Posture.* 1999;9(3):207–231.
13. Vrieling AH, van Keeken HG, Schoppen T, et al. Obstacle crossing in lower limb amputees. *Gait Posture.* 2007;26(4):587–594.
14. Buckley JG, O'Driscoll D, Bennett SJ. Postural sway and active balance performance in highly active lower-limb amputees. *Am J Phys Med Rehabil.* 2002;81(1):13–20.
15. Miller WC, Deathe AB, Speechley M, Koval J. The influence of falling, fear of falling, and balance confidence on prosthetic mobility and social activity among individuals with a lower extremity amputation. *Arch Phys Med Rehabil.* 2001;82(9):1238–1244.
16. Miller WC, Speechley M, Deathe B. The prevalence and risk factors of falling and fear of falling among lower extremity amputees. *Archives of Physical Medicine and Rehabilitation.* 2001;82(8):1031–1037.
17. Dougherty PJ. Long-term follow-up of unilateral transfemoral amputees from the Vietnam war. *J Trauma.* 2003;54(4):718–723.

18. Hagberg K, Branemark R. Consequences of non-vascular transfemoral amputation: a survey of quality of life, prosthetic use and problems. *Prosthet Orthot Int.* 2001;25(3):186–194.
19. Michael JW. Modern prosthetic knee mechanisms. *Clin Orthop Relat Res.* 1999(361):39–47.
20. van de Veen PG. *Above-Knee Prosthesis Technology.* Enschede, The Netherlands: P.G. van de Veen Consultancy; 2001.
21. Berry D. Microprocessor prosthetic knees. *Phys Med Rehabil Clin N Am.* 2006;17(1):91–113,vii.
22. Darling DT. *Automatic Damping Profile Optimization for Computer Controlled Above-Knee Prostheses* [master's thesis]. Cambridge: Massachusetts Institute of Technology; 1978.
23. Grimes DL. *An Active Multi-Mode Above-Knee Prosthesis Controller* [dissertation]. Cambridge: Massachusetts Institute of Technology; 1979.
24. Hafner BJ, Smith DG. Differences in function and safety between Medicare Functional Classification Level-2 and -3 transfemoral amputees and influence of prosthetic knee joint control. *J Rehabil Res Dev.* 2009;46(3):417–433.
25. Hafner BJ, Willingham LL, Buell NC, Allyn KJ, Smith DG. Evaluation of function, performance, and preference as transfemoral amputees transition from mechanical to microprocessor control of the prosthetic knee. *Arch Phys Med Rehabil.* 2007;88(2):207–217.
26. Kahle JT, Highsmith MJ, Hubbard SL. Comparison of nonmicroprocessor knee mechanism versus C-Leg on Prosthesis Evaluation Questionnaire, stumbles, falls, walking tests, stair descent, and knee preference. *J Rehabil Res Dev.* 2008;45(1):1–14.
27. Seymour R, Engbretson B, Kott K, et al. Comparison between the C-leg microprocessor-controlled prosthetic knee and non-microprocessor control prosthetic knees: a preliminary study of energy expenditure, obstacle course performance, and quality of life survey. *Prosthet Orthot Int.* 2007;31(1):51–61.
28. Jepson F, Datta D, Harris I, Heller B, Howitt J, McLean J. A comparative evaluation of the Adaptive knee and Catech knee joints: a preliminary study. *Prosthet Orthot Int.* Mar 2008;32(1):84–92.
29. Berry D, Olson MD, Larntz K. Perceived stability, function and satisfaction among transfemoral amputees using microprocessor and nonmicroprocessor controlled prosthetic knees: a multicenter survey. *J Prosthet Orthot.* 2009;21(1):32–42.
30. Stevens PM, Carson R. Case Report: Using the activities-specific balance confidence scale to quantify the impact of prosthetic knee choice on balance confidence. *J Prosthet Orthot.* 2007;19(4):114–116.
31. Datta D, Howitt J. Conventional versus microchip controlled pneumatic swing phase control for trans-femoral amputees: user's verdict. *Prosthet Orthot Int.* 1998;22(2):129–135.
32. Gerzeli S, Torbica A, Fattore G. Cost utility analysis of knee prosthesis with complete microprocessor control (C-leg) compared with mechanical technology in trans-femoral amputees. *Eur J Health Econ.* 2009;10(1):47–55.
33. Kaufman KR, Levine JA, Brey RH, McCrady SK, Padgett DJ, Joyner MJ. Energy expenditure and activity of transfemoral amputees using mechanical and microprocessor-controlled prosthetic knees. *Arch Phys Med Rehabil.* 2008;89(7):1380–1385.
34. Seelen H, Hemmen B, Schmeets A, Ament A, Evers S. Cost and consequences of a prosthesis with an electronically stance and swing phase controlled knee joint. *Technol Disabi.* 2009;21:25–34.
35. Klute GK, Berge JS, Orendurff MS, Williams RM, Czerniecki JM. Prosthetic intervention effects on activity of lower-extremity amputees. *Arch Phys Med Rehabil.* 2006;87(5):717–722.
36. Williams RM, Turner AP, Orendurff M, et al. Does having a computerized prosthetic knee influence cognitive performance during amputee walking? *Arch Phys Med Rehabil.* 2006;87(7):989–994.
37. Heller B, Datta D, Howitt J. A pilot study comparing the cognitive demand of walking for transfemoral amputees using the Intelligent Prosthesis with that using conventionally damped knees. *Clin Rehabil.* 2000;14:518–522.
38. Legro MW, Reiber GD, Smith DG, del Aguila M, Larsen J, Boone D. Prosthesis evaluation questionnaire for persons with lower limb amputations: assessing prosthesis-related quality of life. *Arch Phys Med Rehabil.* 1998;79(8):931–938.
39. Ware JE, Jr., Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care.* 1992;30(6):473–483.
40. Orendurff MS, Segal AD, Klute GK, McDowell ML, Pecoraro JA, Czerniecki JM. Gait efficiency using the C-Leg. *J Rehabil Res Dev.* 2006;43(2):239–246.
41. Kirker S, Keymer S, Talbot J, Lachmann S. An assessment of the intelligent knee prosthesis. *Clin Rehabil.* 1996;10:267–273.
42. Brodtkorb TH, Henriksson M, Johannesen-Munk K, Thidell F. Cost-effectiveness of C-leg compared with non-microprocessor-controlled knees: a modeling approach. *Arch Phys Med Rehabil.* 2008;89(1):24–30.
43. Johansson JL, Sherrill DM, Riley PO, Bonato P, Herr H. A clinical comparison of variable-damping and mechanically passive prosthetic knee devices. *Am J Phys Med Rehabil.* 2005;84(8):563–575.
44. Schmalz T, Blumentritt S, Jarasch R. Energy expenditure and biomechanical characteristics of lower limb amputee gait: the influence of prosthetic alignment and different prosthetic components. *Gait Posture.* 2002;16(3):255–263.
45. Buckley JG, Spence WD, Solomonidis SE. Energy cost of walking: comparison of "intelligent prosthesis" with conventional mechanism. Arch Phys Med Rehabil. 1997;78(3):330–333.
46. Taylor MB, Clark E, Offord EA, Baxter C. A comparison of energy expenditure by a high level trans-femoral amputee using the Intelligent Prosthesis and conventionally damped prosthetic limbs. *Prosthet Orthot Int.* 1996;20(2):116–121.
47. Ganguli S, Datta SR, Chatterjee BB, Roy BN. Metabolic cost of walking at different speeds with patellar tendon-bearing prosthesis. *J Appl Physiol.* 974;36(4):440–443.
48. Segal AD, Orendurff MS, Klute GK, et al. Kinematic and kinetic comparisons of transfemoral amputee gait using C-Leg and Mauch SNS prosthetic knees. *J Rehabil Res Dev.* 2006;43(7):857–870.
49. Datta D, Heller B, Howitt J. A comparative evaluation of oxygen consumption and gait pattern in amputees using Intelligent Prostheses and conventionally damped knee swing-phase control. *Clinical Rehabilitation.* 2005;19:398–403.
50. Herr H, Wilkenfeld, A. User-adaptive control of a magnetorheological prosthetic knee. *Industrial Robot.* 2003;30(1):42–55.
51. Kaufman KR, Levine JA, Brey RH, et al. Gait and balance of transfemoral amputees using passive mechanical and microprocessor-controlled prosthetic knees. *Gait Posture.* 2007;26(4):489–493.