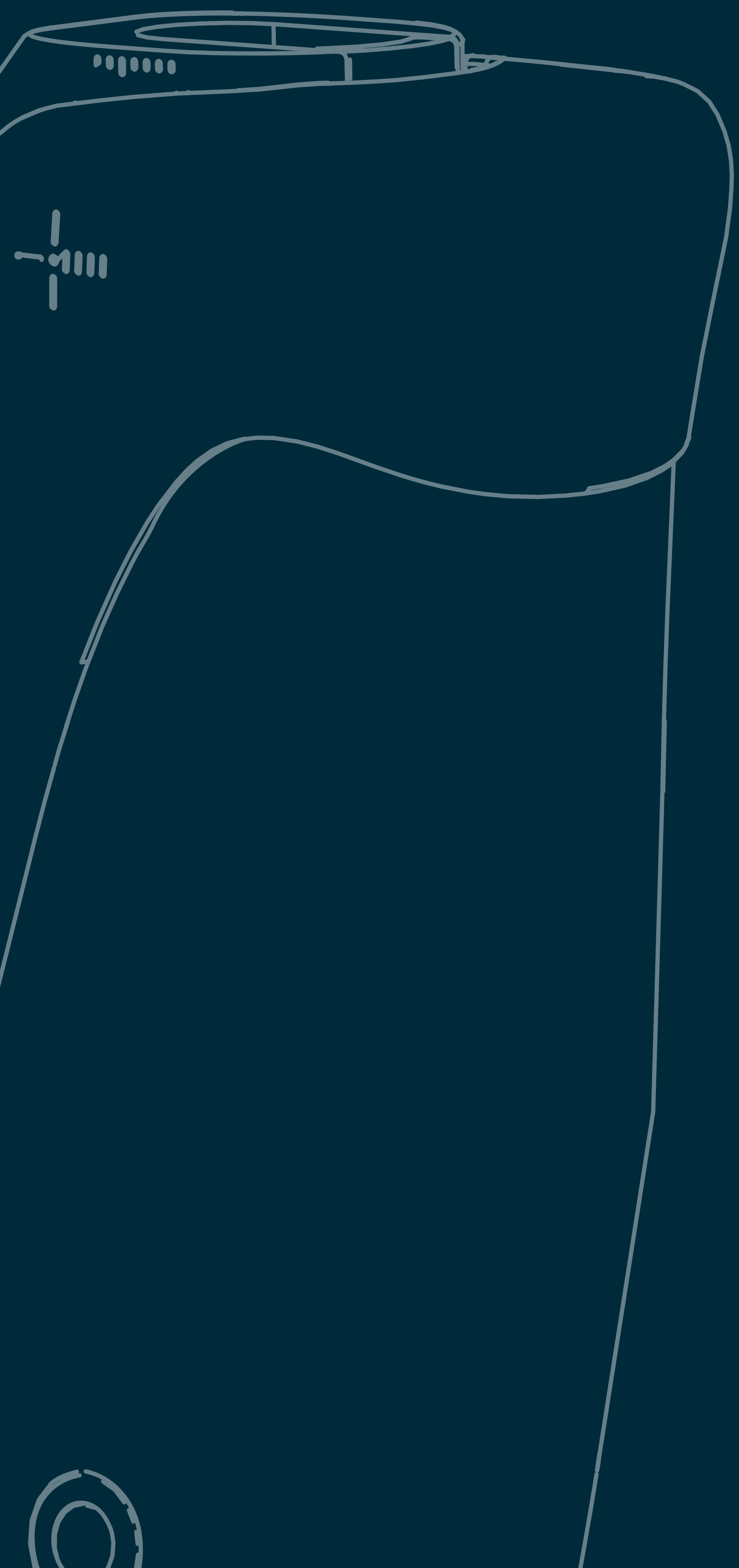
Reducing Amputee Falls With Microprocessor Knees

Blatchford



Reducing Amputee Falls With Microprocessor Knees

The loss of a limb above the knee creates difficulties with balance and stability. Some prosthetic knees are designed to reduce the risks of falling using advanced microprocessor-control technology.

The Challenges of Transfemoral Amputation

The challenges faced by lower limb amputees often increase in difficulty with higher amputation levels. Transfemoral amputees have lost two major joints – the knee and the ankle – along with all the muscle control around those joints, which makes it much more difficult to control their limbs. Consequently, common, everyday activities like walking, require a lot of strength and exertion from the residual hip in order to control stability and create momentum to ensure their prosthetic foot is in the right position to transfer weight to. If the limb swings through too slowly, the foot won't be in the right position; too fast and they might feel a jerking action as the prosthetic knee hits its mechanical, extension stop. This not only makes walking at different speeds a challenge, but also changing speed.

As a result, it is common to see compensatory movements when using a prosthesis, such as spending a longer time on the sound limb when walking, hiking the hips to ensure enough ground clearance to avoid a trip, or even circumduction of the prosthetic leg – that is, swinging it in an arc sideways, again, as a way of avoiding catching it on the ground. All this extra movement makes walking less energy efficient and it is considerably more tiring for transfemoral prosthesis users, compared to non-amputees[1–10]. Research has reported this energy increase as ranging from 20% for active, military amputees[1] to 119% for older, vascular amputees[2], often depending on the speed of walking[3,4].

Both the loss of muscular control and the increase in energy expenditure are contributing factors to what is arguably the most serious concern for transfemoral prosthesis users: falling. Research reports as many as 64% of transfemoral amputees fall at least once a year[11,12]. This is higher than the equivalent reported rates for transtibial amputees[11,12] (43-53%). As well as the greater loss of control and using more energy to perform daily activities, a higher amputation level means the whole-body center-of-mass becomes higher, making the person inherently less stable.

64%

of transfemoral amputees fall at least once a year[11]

The Consequences of Falling

Obviously, falls can result in injuries. It has been reported that, in the lower limb amputee population, half of all falls will result in a soft tissue injury of some kind[12] but they can also have more serious consequences such as broken bones[13,14], some requiring hospitalisation[12], and head injuries, which in the worst cases have the potential to be fatal[13,14].

As well as being traumatic for the individual, such injuries are expensive for healthcare providers too. Researchers looked at the direct medical expenses for transfemoral amputees in the US for the six-month period following a fall[15]. The average cost was over $25,000 but could be up to nearly $39,000. If a transfemoral amputee had to be admitted to the emergency department after a fall, that alone cost an average of approximately $18,000, sometimes going as high as $53,000.

$25,000

The average 6-month cost of a transfemoral amputee in the US, who requires medical treatment following a fall[15]

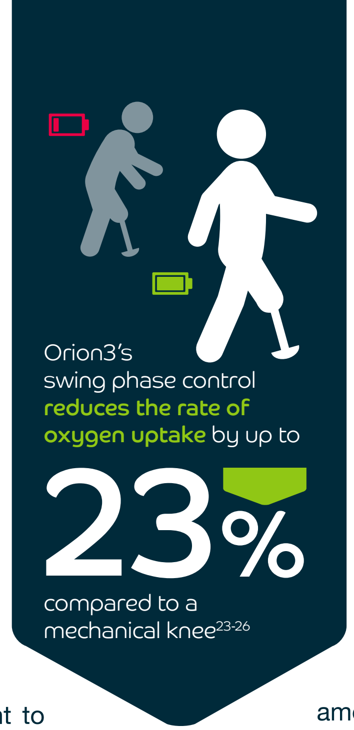
Regardless of whether physical injuries occur or not, there can also be psychological impacts of falling. Nearly half of all lower limb amputees say they worry about falling[16]. Six out of ten say that falls affect their daily lives[12], making them less confident when performing different activities, or impacting their choices on where to walk, such as deliberately avoiding steps or slopes.

Whether it be physical or mental, the consequences of falling are problematic. Prosthesis rejection, through fear or the inability to use the limb, can lead to social withdrawal and a loss of independence, both of which can have a drastic impact on a person's quality-of-life[11,17–20].

Prosthetic Knee Design

For many years, prosthetic knee design has sought to help to mitigate the risk of falling. The polycentric designs, proposed in the 1970s[21], changed the geometry of the knee, making it inherently more stable and increased ground clearance during swing phase. However, the most significant advances in technology have been since the introduction of microprocessor control in the early 1990s and the subsequent evolutionary stages of this technology.

The first microprocessor knees (MPK) focused on swing phase control, mimicking the body's natural propensity to adapt joint kinematics and find the most energy efficient way of walking at different speeds[22]. Through a calculated balance of force applied to extend the knee and the damping applied at the end of swing, MPKs could be programmed to adapt their movement to the needs of the user. Studies evaluating these devices measured up to 23% reductions in energy costs when using MPKs[23–26], compared to mechanical designs. Patients have also reported feeling less tired, being able to walk faster and finding it easier to walk at different speeds[27].

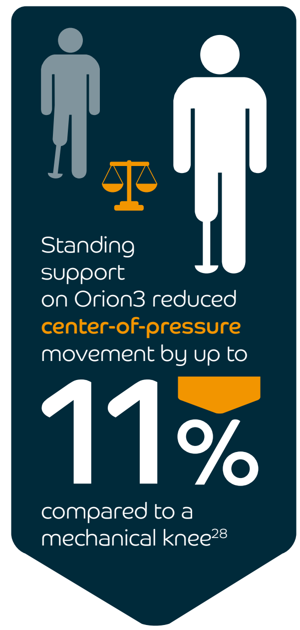


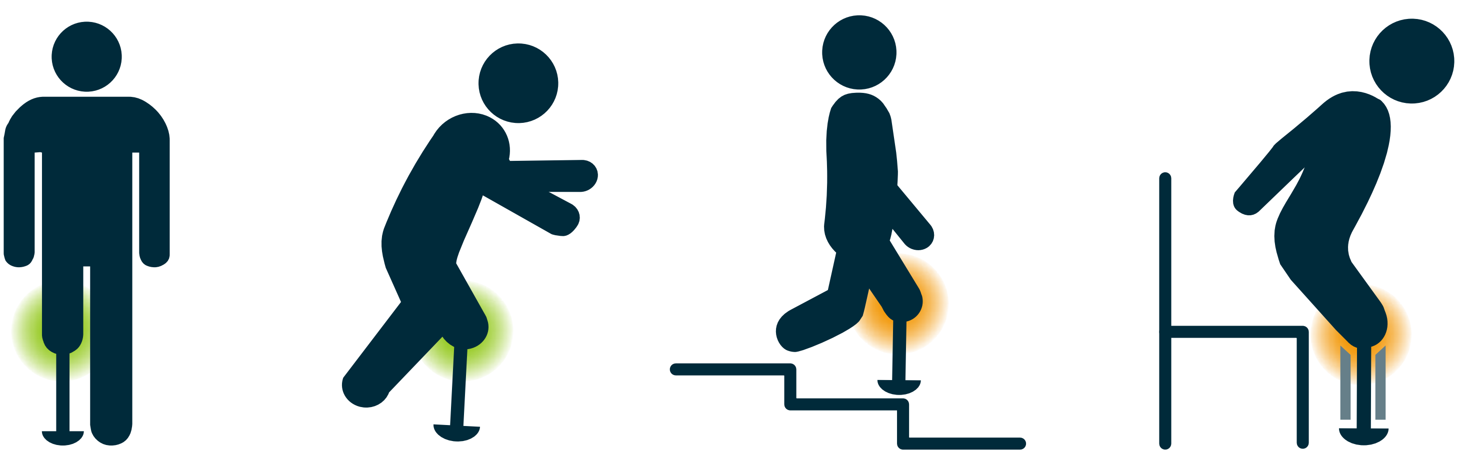
The next evolution in MPKs added microprocessor control to stance phase, in particular providing bodyweight support and stability. The knee could detect that the user was bearing their weight on their prosthesis and so the resistance to flexion would be increased, ensuring that the knee did not buckle or collapse, leading to a fall. This intelligence was also used to determine when this resistance could be lowered to allow the knee to flex in swing phase and ensure adequate ground clearance to avoid a trip.

Blatchford's Orion3 is one of the latest generation of MPKs that has even more features to adapt to different activities and improve user safety. For example, when walking, if a trip or stumble occurs, the knee will provide extra support when it is loaded again, allowing the user to catch themselves and to recover.

Other types of walking are also considered, such as walking downstairs. During this action, the knee flexes more than during level ground walking and the wearer's center-of-mass is further from the pivot point, creating a larger turning moment at the knee and slowing the movement down. This yield mechanism is designed to provide the right level of bodyweight support for the amount of knee flexion, while also allowing movement so the action can be completed. This same mechanism is used for other everyday actions, such as sitting down into a chair.

Perhaps even more fundamental is the simple action of standing still. When a prosthetist aligns a limb in clinic, they aim to reduce the amount of effort required by the wearer to maintain balance and good posture. However, sometimes real-world environmental factors, such as uneven and sloped surfaces, can make it more difficult and require compensatory movements to get the foot flat on the ground. Orion3 is programmed to detect when the wearer is standing still. In this instance, the knee allows weight-bearing by selecting a very high resistance, even if the knee is already flexed. Research has reported that, when users stand on slopes, this standing support can reduce postural sway – an indicator of poor balance – by up to 11%[28].





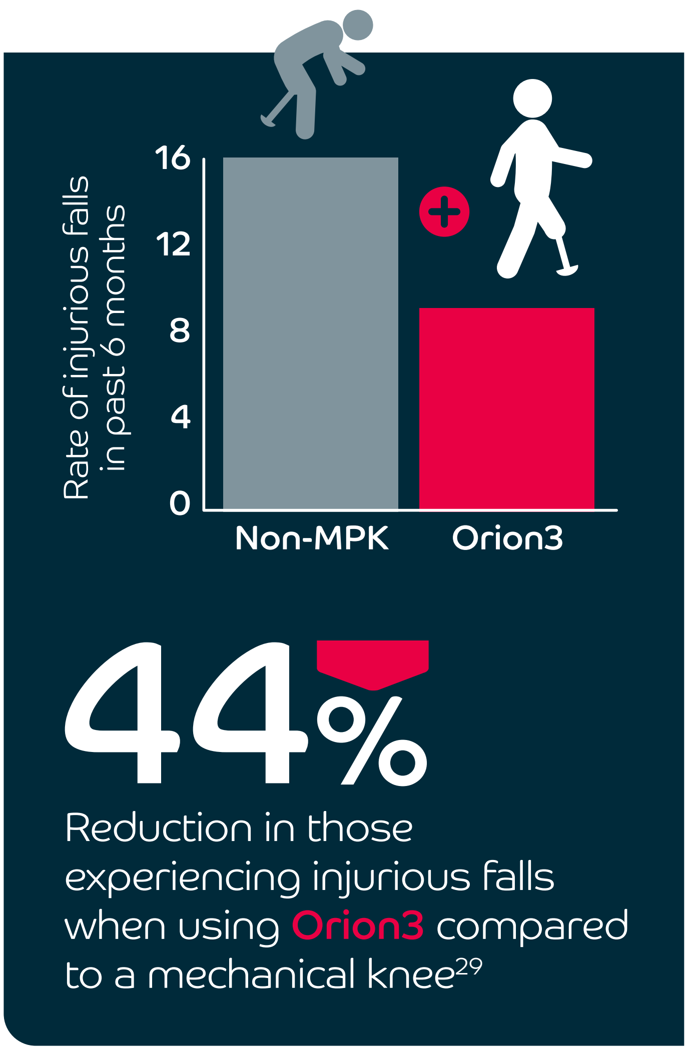
Orion3 offers **high resistance** for stability and a **yield mechanism** to enhance support for daily activities

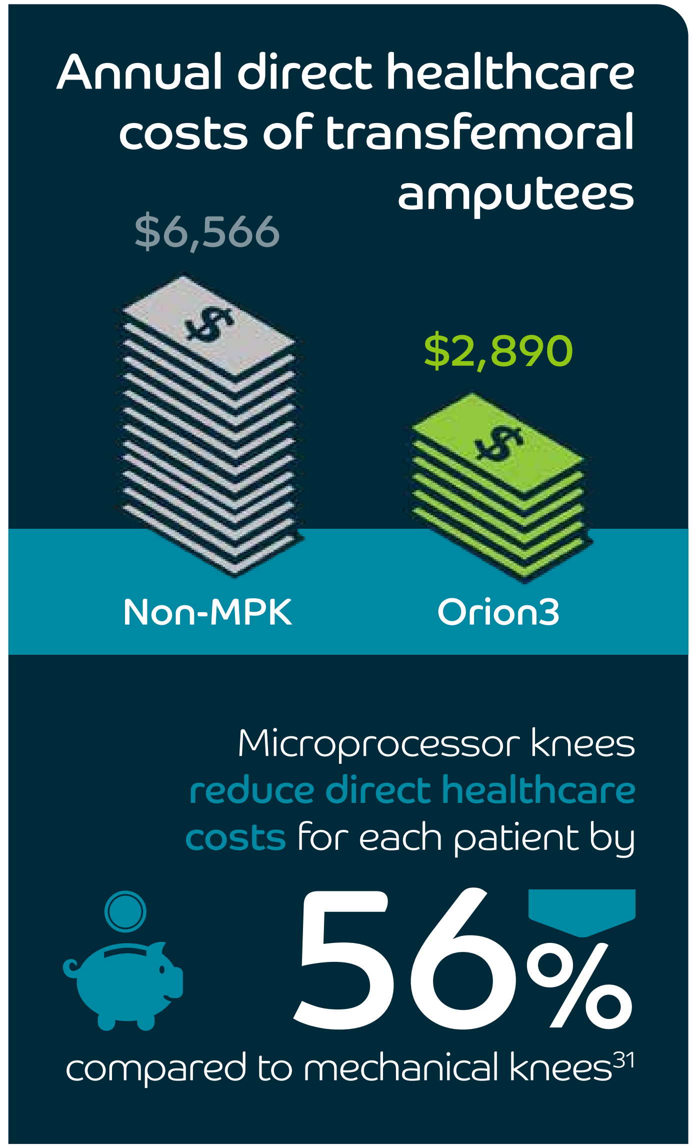
The Outcomes for Patients

These advancements – walking speed adaptation, reduced energetic effort for the user, intelligent bodyweight support, enhanced standing balance and stumble recovery – all contribute to the widely-held belief that the key benefit of MPKs is that they reduce the likelihood of a fall. One of the largest prosthetics studies of its kind looked at measuring this directly by retrospectively analyzing the records of 602 MPK users from different clinics in the US[29]. The researchers divided the participants by MPK model and noted the proportion of users of each type that had experienced a fall, leading to injury, in the previous six months. The results were then compared to previously reported data for a group of non-MPK, mechanical knee users[30].

Orion3 users were significantly less likely to have an injurious fall than non-MPK users[29]. In fact, the proportion of Orion3 users reporting an injurious fall was lower than that of the mechanical knee users by 44% and 8% less than the average calculated across all MPK users[29].

While clearly beneficial to the patients themselves, the other significance of this finding is its health economics implications. Using reported data for the likelihood of falling, the chance of injury and the estimated healthcare costs of such events, researchers can build simulations to predict the outcomes of prescribing MPKs compared to those with mechanical knees over a ten year period[31].





The results of this simulation showed that the biggest impact on healthcare costs was that MPKs significantly reduced the probability of an injurious fall[31]. Annual direct healthcare costs were reduced by 56%, from $6566 per patient with a mechanical knee to $2890 per patient for MPK users. Indirect costs, such as lost wages, paying for carers and transport, were also reduced. What's more, the incidence of falls-related deaths decreased for the MPK simulations, meaning that if 1000 amputees were observed for a year, MPK prescription would save 11 lives. For these reasons, the researchers concluded that MPKs are a justifiable, if not favorable, prescription and are cost-effective for healthcare providers.

Summary

The evidence shows that not only are MPKs effective at improving patient mobility and significantly reducing the occurrence of falls, but they make financial sense too for healthcare providers. The existing body of research makes a strong case for the prescription of MPKs for patients.

References

1. Jarvis HL, Bennett AN, Twiste M, et al. Temporal Spatial and Metabolic Measures of Walking in Highly Functional Individuals With Lower Limb Amputations. Arch Phys Med Rehabil 2017; 98: 1389–1399.
2. Waters R, Perry J, Antonelli D, et al. Energy cost of walking of amputees: the influence of level of amputation. J Bone Jt Surg Am 1976; 58: 42–46.
3. Jaegers SM, Vos LD, Rispens P, et al. The relationship between comfortable and most metabolically efficient walking speed in persons with unilateral above-knee amputation. Arch Phys Med Rehabil 1993; 74: 521–525.
4. Genin JJ, Bastien GJ, Franck B, et al. Effect of speed on the energy cost of walking in unilateral traumatic lower limb amputees. Eur J Appl Physiol 2008; 103: 655.
5. Gitter A, Czerniecki J, Weaver K. A reassessment of center-of-mass dynamics as a determinate of the metabolic inefficiency of above-knee amputee ambulation. Am J Phys Med Rehabil 1995; 74: 337–338.
6. Russell Esposito E, Rábago CA, Wilken J. The influence of traumatic transfemoral amputation on metabolic cost across walking speeds. Prosthet Orthot Int 2018; 42: 214–222.
7. Huang CT, Jackson JR, Moore NB, et al. Amputation: energy cost of ambulation. Arch Phys Med Rehabil 1979; 60: 18–24.
8. 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: 255–263.
9. Carse B, Scott H, Brady L, et al. A characterisation of established unilateral transfemoral amputee gait using 3D kinematics, kinetics and oxygen consumption measures. Gait Posture 2020; 75: 98–104.
10. Traugh GH, Corcoran PJ, Reyes RL. Energy expenditure of ambulation in patients with above-knee amputations. Arch Phys Med Rehabil 1975; 56: 67–71.
11. Gauthier-Gagnon C, Grisé M-C, Potvin D. Enabling factors related to prosthetic use by people with transtibial and transfemoral amputation. Arch Phys Med Rehabil 1999; 80: 706–713.
12. Kulkarni J, Wright S, Toole C, et al. Falls in patients with lower limb amputations: prevalence and contributing factors. Physiotherapy 1996; 82: 130–136.
13. Alexander BH, Rivara FP, Wolf ME. The cost and frequency of hospitalization for fall-related injuries in older adults. Am J Public Health 1992; 82: 1020–1023.
14. Sterling DA, O'Connor JA, Bonadies J. Geriatric falls: injury severity is high and disproportionate to mechanism. J Trauma Acute Care Surg 2001; 50: 116–119.
15. Mundell B, Kremers HM, Visscher S, et al. Direct medical costs of accidental falls for adults with transfemoral amputations. Prosthet Orthot Int 2017; 41: 564–570.
16. Miller WC, Speechley M, Deathe B. The prevalence and risk factors of falling and fear of falling among lower extremity amputees. Arch Phys Med Rehabil 2001; 82: 1031–1037.
17. Hunter SW, Batchelor F, Hill KD, et al. Risk factors for falls in people with a lower limb amputation: a systematic review. PM&R 2017; 9: 170–180.
18. Stevens PM. Prioritizing Primary Outcomes in Prosthetic Rehabilitation: Observations from Recent Evidence. JPO J Prosthet Orthot 2021; 33: 82–87.
19. Miller WC, Deathe AB. The influence of balance confidence on social activity after discharge from prosthetic rehabilitation for first lower limb amputation. Prosthet Orthot Int 2011; 35: 379–385.
20. Costs of Falls Among Older Adults | Home and Recreational Safety | CDC Injury Center, http://www.cdc.gov/homeandrecreationalsafety/falls/fallcost.html (accessed 18 August 2016).
21. Radcliffe CW. The Knud Jansen Lecture: Above-knee prosthetics. Prosthet Orthot Int 1977; 1: 146–160.
22. Ralston HJ. Energy-speed relation and optimal speed during level walking. Eur J Appl Physiol 1958; 17: 277–283.
23. Chin T, Sawamura S, Shiba R, et al. Energy expenditure during walking in amputees after disarticulation of the hip. Bone Jt J 2005; 87: 117–119.
24. 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. Clin Rehabil 2005; 19: 398–403.
25. Buckley JG, Spence WD, Solomonidis SE. Energy cost of walking: comparison of "intelligent prosthesis" with conventional mechanism. Arch Phys Med Rehabil 1997; 78: 330–333.
26. Taylor MB, Clark E, Offord EA, et al. 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: 116–121.
27. Datta D, Howitt J. Conventional versus microchip controlled pneumatic swing phase control for trans-femoral amputees: user's verdict. Prosthet Orthot Int 1998; 22: 129–135.
28. McGrath M, Laszczak P, Zahedi S, et al. 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.
29. Campbell JH, Stevens PM, Wurdeman SR. OASIS 1: Retrospective analysis of four different microprocessor knee types. J Rehabil Assist Technol Eng 2020; 7: 2055668320968476.
30. Wurdeman SR, Miller T, Stevens PM, et al. Microprocessor Knee Technology Reduces Odds of Incurring an Injurious Fall for Diabetic/Dysvascular Amputees. JPO J Prosthet Orthot; 32.
31. Chen C, Hanson M, Chaturvedi R, et al. Economic benefits of microprocessor controlled prosthetic knees: a modeling study. J Neuroengineering Rehabil 2018; 15: 62.

800 548 3534 | info@blatchfordus.com
Blatchford Inc., 1031 Byers Road, Miamisburg, Ohio 45342, USA.

@blatchfordUS | blatchfordus.com

1657329870 Iss1 10/21. Information correct at time of print.