# Energy expenditure of walking with energy storage and return feet compared to SACH feet

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**Clinical Question:** Do energy storage and return feet decrease the metabolic cost of walking over SACH feet for patients with unilateral transtibial amputation (TTA)?

Background: People with transtibial amputation tend to expend more metabolic energy to walk than people with intact limbs.[1] Therefore, finding prosthetic interventions that reduce their energetic costs to more normal levels may allow for greater duration and distance of ambulation to enable a prosthetic user to complete more activities of daily living. Different prosthetic feet may be able to influence energetic costs of walking because the prosthetic foot design will determine its ability to provide propulsive push-off, and there is a strong relationship between push-off provided by the trailing limb and metabolic cost of walking.[2]

Energy storage and return (ESAR) feet represent a broad category of prosthetic feet, typically made of a carbon fiber laminate, and intended to store energy during stance phase, which is then returned to increase propulsion towards the end of stance.[3] A Solid Ankle Cushion Heel (SACH) foot is made of foam covering a solid wooden ankle, and this design has a tendency to absorb energy during stance phase with a minimal return for propulsion. Therefore, ESAR feet that are designed to provide more propulsion from the amputated limb have the potential to reduce energetic cost.

Researchers investigate energetic costs using metabolic cost (MC), which can be calculated by measuring the rate of oxygen consumption ($VO_2$) in ml $O_2$/kg/min. Cost of transport (CoT) is defined as the rate of oxygen consumption normalized to body mass and distance traveled (ml $O_2$/kg/m).[1] The purpose here was to examine research that compared the effects of ESAR feet and SACH feet on energy expenditure during walking.

Search Strategy:
Databases searched: Google Scholar, PubMed, oandp.org
Search terms: energy expenditure AND prosthetic feet AND (transtibial OR below knee)
Inclusion/exclusion criteria: English, published after 1990

Synthesis of Results: Four studies were identified and the number of subjects ranged from 8-24.[4,5,6,7] Two studies included people with TTA secondary to both trauma and dysvacular conditions.[4,7] ESAR feet did demonstrate significant decreases in MC in people with TTA due to trauma in only one study at normal walking speeds and across inclines and declines,[4] and at higher than normal walking speeds in a second study.[6]People with TTA due to trauma also increased their self-selected walking speed (SSWS)[4] and walked at lower exercise intensities while using ESAR feet.[5] However, these results were not consistent across all studies. ESAR feet did not significantly reduce CoT[5] or MC [6,7] at normal walking speeds in other studies. Foot type did not alter MC, or SSWS in people with TTA secondary to dysvascular conditions.[4,7] Small sample sizes plagued all studies and this may have led to all studies showing a general trend that ESAR feet reduced MC, CoT, or increased SSWS without all studies finding statistically significant results.[4,5,6,7]

Clinical Message: ESAR feet may have some energetic advantages over SACH feet but the evidence remains weak because it is not consistent across studies. In addition, these benefits seem to be apparent at higher than normal walking speeds, inclines/declines, and for patients with a traumatic cause of amputation. There is limited evidence demonstrating ESAR feet offer reduced metabolic costs of ambulation for people with TTA secondary to dysvascular conditions, but this may have been due to methodological challenges associated with collecting this type of data in a population with compromised cardiovascular systems and the limited statistical power. Future research may utilize newer techniques to quantify metabolic cost instanteously[8] to minimize the amount of walking time for people with dysvascular conditions, increase sample sizes, and blind the subjects as to the type foot they are using.

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## Evidence Table

| | Casillas et al., 1995[4] | Hsu et al., 2006[5] | Schmalz et al., 2002[6] | Torburn et al., 1995[7] |
|---|---|---|---|---|
| **Population** | 24 subjects with TTA (12 traumatic and 12 dysvascular) | 8 subjects with traumatic TTA, > 1 yr. of prosthetic experience | 8 subjects with traumatic TTA able to walk at least 5 km | 16 subjects with TTA (9 traumatic, 7 dysvacular) |
| **Study Design** | Crossover study | Repeated measures, nonrandomized | Crossover study | Crossover study |
| **Intervention** | Proteor foot | Otto Bock 1C40 C-Walk and Ossur Vari-flex. | Otto Bock 1D10, 1D25, 1C40, and Flex Walk II. | Carbon Copy II, Seattle Lite, Quantum, and Flex-Foot |
| **Comparison** | SACH foot | SACH foot | SACH foot | SACH foot |
| **Methodology** | 1 week acclimation to each foot. Measured $VO_2$ during walking on a level surface and a treadmill at 40, 66.67, and 100 m/min if tolerated. Dysvascular subjects did not walk on the treadmill. | 1 month acclimation with each foot. Walked on treadmill at 53.64, 67.05, 80.46, 93.87, 107.28 m/min and SSWS for 4 min each. Monitored $VO_2$, heart rate (HR), and rating of perceived exertion. | Feet tested in random order. Subjects walked on treadmill at 66.67 and 80 m/min for 5 min each. Rested 30 min between trials. Recorded $VO_2$ and HR. | 1 month of acclimation for each foot. Subjects walked on level track at SSWS for 5-20 minutes depending on fatigue. Measured $VO_2$ via Douglas bag, HR, and respiration rate. |
| **Outcomes** | $VO_2$ at rest and all walking conditions. Self-selected walking speed (SSWS) for level surface walking. | $VO_2$, CoT, relative exercise intensity ([exercise HR/age predicted max HR] x100), and rating of perceived exertion. | $VO_2$ and HR. | $VO_2$, HR, respiration rate, stride frequency, distance traveled per trial, and total distance traveled |
| **Key Findings** | Subjects with traumatic amputation had decreased MC on the treadmill while using the Proteor. On level ground their SSWS increased while MC was the same. Subjects with dysvascular amputation showed no significant differences between the two feet. | The Vari-flex had lower relative exercise intensity and rating of perceived exertion than the other two. The ESAR feet demonstrated an insignificant trend to decrease CoT over SACH. Subjects subjectively favored the Vari-flex. | ESAR showed no significant decreases in MC relative to SACH at normal walking speeds but did demonstrate significant differences at the higher (80 m/min) speed. HR similar for all conditions. | MC was not influenced by prosthetic foot design regardless of amputation etiology. |
| **Study Limitations** | Treadmill walking could not be done for subjects with dysvascular amputation.<br>Subjects not blinded to foot type. | Subjects not blinded to foot type. Small sample size meant that apparent advantages of ESAR feet were not statistically significant. | Subjects not blinded to foot type. Only 10 minutes of acclimation. | Statistical power analysis was low due to low sample size. Subjects not blinded to foot type. |

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