Energy Expenditure and Substrate Utilization with Hands-Free Crutches Compared to Conventional Lower-Extremity Injury Mobility Devices

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Abstract

Background: A Hands-Free crutch (HFC) is a relatively new device that can be used during the nonweightbearing period to increase mobility. The primary aim of this investigation was to examine aerobic oxygen consumption ($V.o_2$) and substrate utilization with HFC compared to conventional ambulation devices as well as normal ambulation. A secondary purpose was to quantify perceived exertion, pain, and performance during each ambulation condition.

Methods: Forty participants completed 4 separate 10-minute ambulation conditions around a rectangular course. The order of the ambulation conditions was randomized and consisted of (1) walking, (2) medical knee scooter (MKS), (3) HFC, and (4) axillary crutch (AC). Indirect calorimetry was used to determine $V.o_2$ and the respiratory exchange ratio (RER), an indicator of substrate utilization. Perceived exertion and pain were also assessed using questionnaires.

Results: All mobility devices significantly elevated $V.o_2$ (+35%) compared to walking (13.14 ± 1.70 mL/kg/min; $P < .001$). AC had significantly greater $V.o_2$ requirements (20.26 ± 2.62 mL/kg/min) compared to both the MKS (15.28 ± 2.29 mL/kg/min; $P < .001$) and HFC (15.88 ± 2.03 mL/kg/min; $P < .001$). There was no difference in average $V.o_2$ between MKS and HFC ($P = .368$). Compared to walking (0.78 ± 0.43), RER was significantly elevated in MKS (0.81 ± 0.05, $P < .001$) and AC (0.84 ± 0.06, $P < .001$), but not in HFC (0.79 ± 0.04, $P = .350$). RPE and pain were elevated in all ambulatory conditions (all P values <.001). Pain was significantly greater in AC compared with MKS ($P < .001$) and HFC ($P < .001$).

Conclusion: HFC and MKS share similar $V.o_2$ requirements over a 10-minute ambulation interval and are below those needed in AC. Substrate utilization in HFC was similar to regular walking with a greater reliance on lipid utilization for energy as evidenced by a lower RER. Exertion and pain scores were the most tolerable in HFC and MKS.

Level of Evidence: Level II, prospective comparative study.

Keywords: assistive devices, iWALK, axillary crutches, medical knee scooters

Introduction

Lower extremity injuries such as Achilles tendon rupture as well as ankle fracture are common in recreational and elite athletes, the armed forces, and in the general public.[3,11,27] Achilles tendon rupture, in particular, has risen from 1.8 per 100,000 person-years in 2012 to 2.5 per 100000 person-years in 2016.[12] Further, from 2012 to 2016, the number of ankle fractures in the United States was 673214, with an estimated incidence rate of 4.22 per 10000 person-years.[25] After medical intervention, recovery from lower extremity injury requires a nonweightbearing period at the injured area for approximately 6-8 weeks. Compliance during the nonweightbearing period is critical in order to prevent

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further complications; however, this can be challenging given the requirements needed to complete activities of daily living or other occupational, educational, social, or family-related demands during the recovery time frame.[16]

To assist with compliance during the nonweightbearing period, several mobility aids are available to patients to utilize to help improve quality of life and independence.[24] The most common mobility aid is an axillary crutch (AC) that works to promote physical activity[20]; however, these types of crutches require the use of the hands to ambulate and are often associated with pain[13] and greater energy expenditure compared with traditional walking.[14] The medical knee scooter (MKS) is another mobility device that is commonly used by patients during the nonweightbearing period. MKS is generally associated with less energy expenditure during movement[18]; however, the hands are still required to steer the device, and the surface used while maneuvering can limit utility or lead to complications including falls.[30]

Hands-free crutch (HFC) is a relatively new mobility device that can be used during the musculoskeletal unloading period to increase physical activity and the use of the upper extremity limbs for activities of daily living.[2,13] In 2007, Rambani et al[19] conducted a randomized controlled trial on HFC in patients with injuries that prevented them from using an AC crutch. The average stay in patients using HFC was about 2 days (range 1-5 days) less than patients who did not use the HFC crutch.[19] Further, HFC was associated with greater overall functional assessment scores, increased coping, and a trend toward better lower extremity function scores.[19] Unlike standard axillary crutching, more modern versions of HFC devices allow more normal gait patterns and promote high levels of muscle activation during ambulation.[2] Modern HFC weigh approximately 2.1 kg and would require the user to consistently move that amount of mass as they ambulate in the nonweightbearing period. However, although preliminary data exist on energetics during HFC use,[17] it is currently unknown how aerobic energy expenditure and substrate utilization may differ with HFC ambulation vs conventional lower extremity injury ambulation devices and traditional walking. Differences in aerobic energy expenditure and comfort during ambulation is critical for safety and ease of use while in the nonweightbearing recovery period. The primary aim of this investigation was to examine differences in aerobic oxygen consumption and substrate utilization with HFC compared to other mobility aids and normal ambulation. A secondary purpose was to quantify and compare perceived exertion, pain, and performance during each ambulation condition.

Methods

Study Design

This study was a randomized, within-subject, crossover experimental design. All participants completed 3 sessions:

(1) informed consent/familiarization session, (2) lower extremity injury ambulation practice session, and (3) an experimental testing session. During the informed consent and familiarization session the risks, benefits, and procedures of the study were explained and participants provided written informed consent. Participants also completed a Physical Activity Readiness Questionnaire,[28] deep vein thrombus screening questionnaire (required by human research ethics board at institution),[7] a study-specific exclusion questionnaire and subjects were fitted on the ambulation devices. During the lower extremity injury ambulation practice session, participants were able to get comfortable and proficient with the various ambulation devices and were deemed competent by a member of the research team. During the experimental testing session, height and body mass were measured using a digital scale to the nearest 0.1 kg (Health-o-meter 751KLS, Sunbeam Products, Inc, Boca Rotan, FL), height to the nearest 0.5 cm using a stadiometer (Seca 703 scale; Seca Corporation, Chino, CA), and thigh circumferences were determined using Gulick measuring tape to the nearest 0.1 cm (Fitness Mart, Gay Mills, WI). All participants were then fitted with a portable metabolic system and completed 4 separate 10-minute ambulation conditions over a 30.48-m (100-ft) rectangular course. This duration of ambulation was consistent and even longer than previous research in this area,[6,13,26] and the goal was for subjects to reach steady-state energy utilization (ie, a leveling off of submaximal $V.o_2$ over time).[4] Participants were instructed to complete the ambulation course at a self-selected but safe pace, which could be maintained for the entire 10-minute period without resting. There was a five-minute rest period between each ambulation condition. The order of the ambulation conditions was randomly assigned. Randomization was completed by having each participant randomly draw a coin from a bag, 3 times. Each coin was labeled with one of the conditions and order was determined by the coin selected on each draw. The conditions consisted of (1) walking, (2) MKS (Elenker, Chino, CA), (3) HFC (iWalkFree, Mansfield, ON), and (4) AC (Personal Care Products, China). A photo of the HFC can be viewed elsewhere.[13]

Subjects

Forty participants (25 males, 15 female) ranging in age from 18-45 years (age = 24 ± 5 years, height = 174 ± 7 cm, body mass = 78 ± 14 kg, body mass index = 26 ± 4) were recruited and completed the investigation. Sample size for the study was estimated from previous studies on energy expenditure and substrate utilization with mobility devices.[5,6,18,26] Retrospective analysis determined the sample size of 40 participants was at 100% power with an alpha level of 0.05. Recruitment was completed via electronic advertisements and presentations at the university. Inclusion criteria were as follows: height between 1.52 m (5 ft) and

1.93 m (6 ft 4 in.) and the absence of any lower extremity pain, spine pain, or medical disorders that limited participation in work or exercise in the last 6 months. Additional inclusion included pain-free range of motion of the bilateral lower extremities and spine, the ability to hop, complete a full squat, walk up and down a flight of stairs at normal walking speed without using the handrail, and stand on 1 leg for at least 30 seconds. Exclusion criteria included body mass >122 kg (270 lb), body mass index >30, and maximum thigh circumference at top of leg >0.71 m (28 in.). Additional exclusion included prior lower extremity injury proximal to the ankle requiring surgery or limiting function for greater than 6 weeks, prior back pain that recurred or limited activities for greater than 6 weeks, diagnosed moderate or severe brain injury, diagnosis of a physical or psychological condition that would preclude testing (e.g., cardiac condition, clotting disorder, pulmonary condition), current complaint of pain or numbness in the spine, uncorrected visual or hearing impairment, requiring an assistive device to ambulate, self-report of pregnancy or potential pregnancy, and moderate or high risk of deep vein thrombus on screening form.

Aerobic Oxygen Consumption and Substrate Utilization

Indirect calorimetry was used to measure oxygen utilization ($V.o_2$) and carbon dioxide expiration ($V.co_2$) during 10 minutes of steady-state movement in each ambulation condition using a portable metabolic analyzer (COSMED K5; COSMED Inc, Concord, CA).[29] The $V.o_2$ and $V.co_2$ data were averaged per 60 seconds for analysis and are expressed per unit of time (mL/kg/min) and per unit of distance (mL/kg/m).[6] Substrate utilization during steady-state movement was determined by the respiratory exchange ratio (RER) which was calculated by $V.co_2 / V.o_2$.[29]

Rate of Perceived Exertion and Pain

Perceptual responses were assessed for each ambulation condition. A subjective assessment of rating of perceived exertion (RPE) was collected during the last 30 seconds of each ambulation condition using a 0-10 rating scale.[21] Pain was evaluated immediately following each ambulation condition using a visual analog scale (VAS), which is a widely accepted and repeatable method of measuring pain perception.[23] The VAS used a 10-centimeter line with statements, "no pain" on the far left and "pain as bad as it could be" on the far right. Participants placed a mark at a point on the line corresponding to their rating of pain intensity and verbally described the location of pain to the research team following each 10-minute ambulation condition.

Performance

The total distance completed during each 10-minute ambulation condition was recorded via number of laps completed while moving around the outside of the defined rectangular course. Velocity of self-selected ambulation was calculated as distance (in meters) achieved per 10 minutes.

Statistical Analysis

Mean and SD were used to determine the participants' descriptive information. Parametric analysis of variance with repeated measures was used to determine differences between $V.o_2$ and RER. RPE and Pain data were analyzed via nonparametric Friedman test. An alpha level of 0.05 was used to determine significance and partial eta-squared ($p\eta^2$) effect size was included for additional interpretation; whereby a $p\eta^2$ of 0.2 to 0.12 is considered a small effect, 0.13 to 0.25 is a medium effect, and >0.26 is a large effect.[1] When significance was determined, Sidak post hoc tests were used to evaluate differences between the 4 ambulation conditions. All statistical analyses were performed in SPSS, version 28.0 (IMB Corp, Armonk, NY).

Results

Steady state $V.o_2$ (mL/kg/min) across the 10-minute ambulation period for each condition are shown in Figure 1A. There were significant differences in average $V.o_2$ relative to ambulation time ($P < .001$, $p\eta^2 = 0.77$). The $V.o_2$ for walking, MKS, HFC, and AC were 13.14 ± 1.70, 15.27 ± 2.29, 15.87 ± 2.03, and 20.26 ± 2.62 mL/kg/min, respectively (Figure 1B). All mobility devices significantly elevated average $V.o_2$ relative to ambulation time compared to walking (all P values <.001). AC had significantly greater average $V.o_2$ relative to ambulation time compared to both the MKS ($P < .001$) and HFC ($P < .001$). There was no difference in average $V.o_2$ relative to time between MKS and HFC ($P = .368$). When $V.o_2$ was normalized, per unit of distance during ambulation (in mL/kg/m), there were significant differences among the ambulation conditions ($P < .001$, $p\eta^2 = 0.93$). $V.o_2$ per unit of distance for walking, MKS, HFC, and AC were 0.21 ± 0.34, 0.29 ± 0.06, 0.46 ± 0.11, 0.50 ± 0.09 mL/kg/m, respectively. All mobility devices significantly elevated average $V.o_2$ relative to ambulation distance compared to walking (all P values ≤.001). AC had significantly greater average $V.o_2$ relative to ambulation distance compared to both the MKS ($P = .001$) and HFC ($P = .002$). HFC had a greater average $V.o_2$ relative to distance when compared to MKS ($P < .001$).
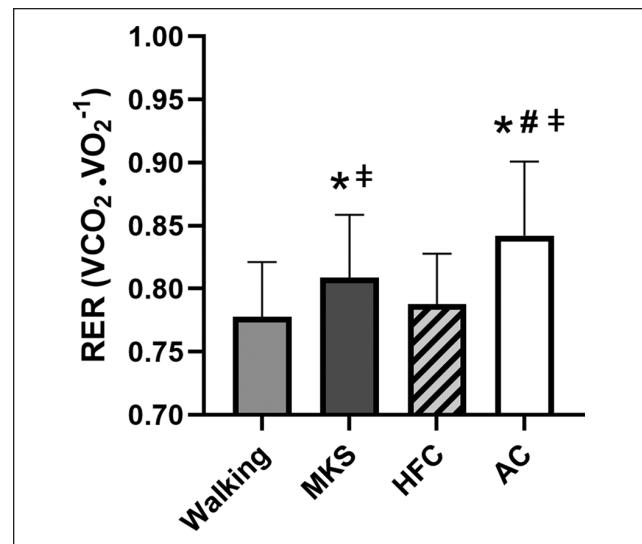
There were significant differences in substrate utilization as evidenced by average RER ($P < .001$, $p\eta^2 = 0.55$). Average RER for walking, MKS, HFC and AC were 0.78 ± 0.43, 0.81 ± 0.05, 0.79 ± 0.04, and 0.84 ± 0.06,
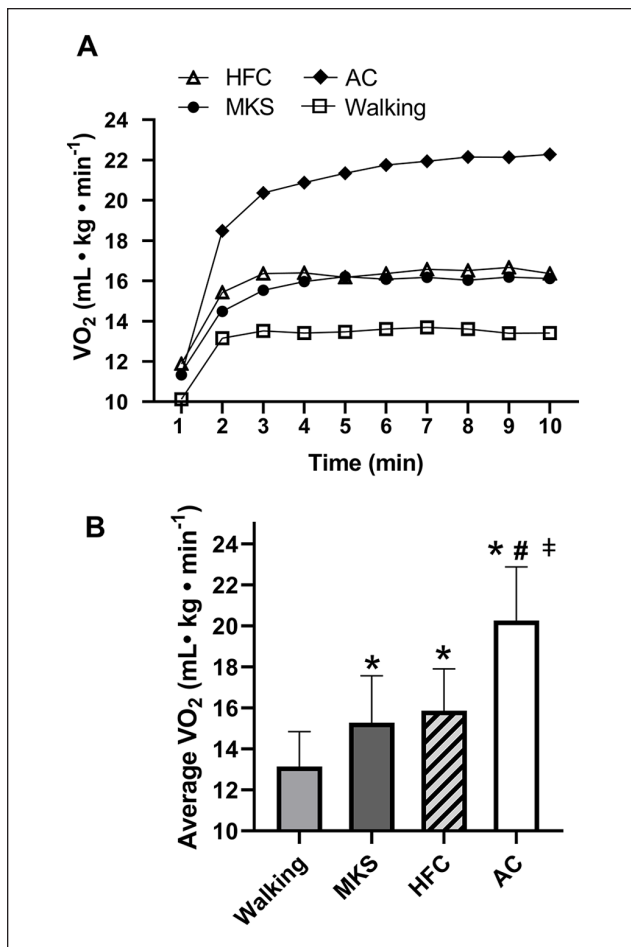
Figure 1. Aerobic energy expenditure (V_{O_2}) during ambulation conditions. (A) Steady-state V_{O_2} during each minute of ambulation. Diamonds = axial crutch, triangle = hands-free crutch, circle = medical knee scooter, square = walking. (B) Average V_{O_2} during 10 minutes of ambulation. *Significantly greater than walking, #significantly greater than medical knee scooter, ‡significantly greater than hands-free crutch. All significance levels $P < .05$.

Figure 2. Average respiratory exchange ratio (RER) during 10 minutes of ambulation. *Significantly greater than walking, #significantly greater than medical knee scooter (MKS), ‡significantly greater than hands-free crutch (HFC). All significance levels $P < .05$.

respectively (Figure 2). Compared to walking, RER was significantly elevated in MKS ($P < .001$) and AC ($P < .001$). There was no difference in RER in HFC compared to walking ($P = .350$). Average RER during AC crutch was also significantly greater than HFC ($P < .001$) and MKS ($P < .001$). Average RER for MKS was significantly greater than HFC ($P < .001$).

There were significant differences in RPE in the different ambulation conditions ($\chi^2 = 95.53$, $P < .001$). Data for RPE following each ambulatory condition are shown are shown in Table 1. Compared to walking, RPE was elevated in all ambulatory conditions (all P values <.001). RPE for AC was significantly greater than MKS ($P < .001$) and

HFC ($P < .001$). RPE for HFC was also significantly greater than MKS ($P = .034$). Pain was reported in 2.5%, 60%, 67.5%, and 90% of the study participants following walking, MKS, HFC, and AC, respectively. There were significant differences in pain in the different ambulation conditions ($\chi^2 = 61.43$, $P < .001$; Table 1). Compared to walking, pain was elevated in all ambulatory conditions ($P < .001$). Pain in AC was significantly greater than MKS ($P < .001$) and HFC ($P < .001$). There were no differences in pain between HFC and MKS ($P = .750$). Of the participants that reported pain, the frequency and general area pain is reported in Table 2.

There were significant differences in distance achieved during the 10-minute ambulation period ($P < .001$, pη^2 = 0.796; Table 1). Compared to walking, the distance achieved during all ambulation conditions was significantly reduced (all P values <.001). MKS had significantly greater distance than HFC ($P < .001$) and AC ($P < .001$). AC distance was significantly greater than HFC ($P < .001$). There were significant differences in self-selected velocity of movement during the 10-minute ambulation period ($P < .001$, pη^2 = 0.796; Table 1). Compared to walking, the self-selected velocity of movement achieved during all ambulation conditions was significantly reduced (all P values <.001; Table 1). MKS had significantly greater self-selected velocity compared with HFC ($P < .001$) and AC ($P < .001$). AC self-selected velocity was significantly greater than HFC ($P < .001$).

Table 1. Rate of Perceived Exertion (RPE), Pain, Distance, and Self-Selected Velocity During Each 10-Minute Ambulation Condition.

Variable	Walking	MKS	HFC	AC
RPE (0-10)	0.55 ± 0.64	2.53 ± 1.75*	3.15 ± 1.75*#	5.02 ± 2.11*#‡
Pain (mm)	0.63 ± 0.28	1.33 ± 1.76*	1.33 ± 1.78*	2.37 ± 1.90*#‡
Distance (m)	632 ± 83	532 ± 107*‡ †	360 ± 79*	415 ± 88*‡
Velocity (m/min)	63 ± 8.4	53 ± 10.8*‡ †	36 ± 7.9*	42 ± 8.8*‡

Abbreviation: AC, axillary crutch; HFC, hands-free crutch; MKS, medical knee scooter.
*Significantly different than Walking, #significantly different than Medical Knee Scooter, ‡significantly different than hands-free crutch, †significantly different than axial crutch. All significance levels $P < .05$.

Table 2. Frequency and Location of Pain Reported After Each Ambulatory Condition.[a]

	Walking	HFC	MKS	AC
Reported no pain	39	13	16	4
Reported pain	1	27	24	36
Quadriceps	0	10	7	0
Hip	0	4	1	1
Knee	0	3	8	0
Leg/shin	0	6	5	3
Armpits	0	0	0	19
Wrist/hand	0	0	0	8
Other	1	2	2	2
Total	1	25	23	33

Abbreviations: AC, axillary crutch; HFC, hands-free crutch; MKS, medical knee scooter.
[a]Frequency and location of pain was verbally described to the research team following each 10-minute ambulation condition.

Discussion

The primary aim of this investigation was to examine differences in aerobic V.o$_2$ and substrate utilization with HFC compared to other mobility aids and normal ambulation. Consistent with previous studies,[5,6,18,26] V.o$_2$ relative to ambulation time was significantly higher (+35%) using the various ambulation devices compared with walking. The V.o$_2$ for walking averaged 13.14 ± 1.70 mL/kg/min, which converts to a metabolic equivalent of 3.7 (1 MET =3.5 mL/kg/min).[9] Thus, the task intensity would be classified as light (MET range 1.6-3.9) in men and moderate intensity in women (MET range 2.8-4.3).[9] AC had a significantly greater V.o$_2$ demand, which was 54% greater than walking. The average V.o$_2$ of AC was 20.26 ± 2.62 mL/kg/min, which corresponds to a MET value of 5.7,[9] which is at the high-end range of moderate intensity in men (MET range 4.0-5.9) and at the high end range of heavy intensity in women (MET range 4.4-5.9).[9] For task intensity comparison in both men and women, walking upstairs has a MET classification of 4.7 and rowing at 4 km/h (2.4 mile/h) has a MET classification of 5.5.[9] This indicates that AC use over 10 minutes is consistent above these activity intensities.

One novel finding of the investigation was that the V.o$_2$ demand above that of walking during HFC (+21%) was not significantly different than MKS (+16%). V.o$_2$ demand in HFC (15.27 ± 2.29 mL/kg/min or 4.4 METs) and in MKS (15.87 ± 2.03 mL/kg/min or 4.5 METs) would both be considered at the lower-end range of moderate intensities in men (MET range 4.0-5.9) and at the lower-end range of heavy for women (MET range 4.4-4.9).[9] For task intensity comparison in both men and women walking between 5 and 7 km/h (3.1-4.3 mile/h) has MET classification between 3.2 and 5.3, which suggests HFC and MKS fall near the lower end of these activity classification intensities.[9] Previous suggested benefits of an MKS have included lower energy expenditure and the ability to free up the hands when not steering or controlling the device.[15,22] Our findings suggest that HFC also demands less aerobic energy relative to time than AC and allows for complete availability of the hands. Having an aerobic energy expenditure similar or as close to normal walking would be beneficial for patients recovering from injury by encouraging physical activity and enhancing the ability to complete activities associated with daily living.

Although the vast majority of studies examining metabolic characteristics of ambulation devices would use fixed time in the research design in order to determined steady-state V.o$_2$ values for comparison,[6,10,13] this strategy is not without limitations.[6] The distance completed during ambulation may vary across the duration of an ambulation trial based on energetic requirements and pain. To address this in the current study, V.o$_2$ was normalized to the distance traveled (meters) over the 10-minute ambulation period.[6] AC had had the greatest aerobic energy requirement per distance traveled (+138%) relative to walking followed by HFC (+119%). Both AC and HFC had greater relative aerobic energy requirements than MKS. The MKS also had greater aerobic energy requirements when normalized to distance (+38%) than walking, but was the closest reflection to walking relative to distance in this simulation study.

Holder et al[6] suggest that clinicians should be most interested in oxygen utilization per distance when examining ambulatory devices compared with oxygen utilization relative to a fixed time. Previously, Holder et al[6] concluded AC

should be used in patients because it had the lowest oxygen cost per unit of distance (0.40 mL/kg/m) compared to standard walkers (0.60 mL/kg/m) and wheeled walkers (0.60 mL/kg/m). In the current investigation, AC oxygen cost per unit of distance was slightly lower than the abovementioned study (0.50 mL/kg/m). However, oxygen cost in MKS (0.29 mL/kg/m) was the lowest followed by HFC (0.46 mL/kg/m), which may have future implications for clinical decisions on which mobility device may be recommended in the future.

Substrate utilization can be characterized during steady-state physical activity through the interpretation of RER, which represents the ratio of carbon dioxide production to oxygen consumption.[8] An RER >0.90 indicates significant anaerobic metabolism, and as it shifts to ≥1.00, it suggests nearly full carbohydrate energy usage to fuel ambulation.[4] Previous research has shown that RER elevates above 1.00 in fracture patients using crutches during as little as 5 minutes of ambulation compared with normal walking (RER = 0.81).[29] In the current study, where healthy subjects underwent a disuse simulation, AC had the greatest RER (0.84) during ambulation, which suggests approximately 47% of aerobic energy demand was met via carbohydrate stores and 53% were derived from lipid oxidation.[4] The MKS (RER = 0.81) was significantly lower than AC yet higher than HFC (RER = 0.79) and suggests 33% of aerobic energy demand was from carbohydrates and 66% was from lipid oxidation.[4] We speculate that RER was greater in MKS compared to HFC because they were moving at a higher velocity (53 m/min vs 36 m/min, respectively) and additional carbohydrate contribution (ie, glycolysis) was required to propel the participants forward using the ambulatory leg. Another interesting finding was that RER for HFC and walking (RER = 0.78) were not significantly different from each other, suggesting approximately 26% to 29% of aerobic energy from carbohydrate and 70% to 73% from fat oxidation.[4] These findings indicate that HFC ambulation may allow users to resist fatigue as the duration of work continues given a greater reliance on fat oxidation to fuel ambulation. This may be advantageous during occupational settings or with prolonged activities of daily living where hands are required to perform work.

A secondary purpose of this investigation was to quantify and compare perceived exertion, pain, and performance during each ambulation condition. Previous research has shown HFC led to nearly half the level of perceived exertion (2.8 out of 10) over a 6-minute walk compared to AC (5.3 out of 10).[13] The MKS have also demonstrated reduced perceived exertion (3.5 out of 10) compared to AC (6.2 out of 10).[10] Our data are consistent with previous studies as all ambulation devices led to higher RPE scores compared with walking, with AC (5.0 out of 10) reporting greater RPE ratings compared with both MKS (2.5 out of 10) and HFC (3.2 out of 10). We speculate that RPE was higher in HFC

given both lower limbs required neuromuscular activation for ambulation, whereas MKS only required unilateral neuromuscular activation. Pain during ambulation generally mirrored RPE as all mobility devices elevated pain compared to walking. Pain was reported in 90% (36 of 40 participants) of the study participants following AC and was nearly 2-fold compared to HFC and MKS. Of those that reported pain in AC, 58% (19 of 33) pain locations were in the armpit region and 24% (8 of 33) of pain locations were in the hands and wrists. In contrast, 60% (24 of 40 participants) and 67.5% (27 of 40 participants) reported pain in MKS and HFC, respectively. In those that reported pain in HFC, 40% (10 of 25) of pain locations were in the quadriceps and 24% (6 of 25) of pain locations were reported in the leg and shin of the right (disuse leg). In those that reported pain in MKS, 34% (8 of 23) of pain locations were in the knee and 30% (7 of 10) was in the quadriceps in the right (disuse leg). Both perceived exertion and pain can influence the performance (ie, total distance) of ambulation when combined with energy expenditure rates as well as substrate utilization. In a recent comparison of HFC to AC over 6 minutes, HFC distance was ~9% less than what was completed by AC (272 m vs 299 m, respectively).[13] Consistent with the aforementioned study,[13] we also found the HFC completed less distance, which was ~14% less than AC (360 m vs 415 m, respectively). The MKS had the greatest distance, which was only 14% less than regular walking. However, it should be noted that during ambulation there were no barriers such as extension cords, steps, curbs, or terrain changes that would impede wheeled motion or provide more friction. As previously suggested,[6] distance completed over time is also related to the combination of stride length and velocity of movement, which may have favored AC over HFC in the current investigation given the body is propeled forward on the crutch axis, and this may be greater than a natural gait length, which is required during HFC.

One strength of the study was the ability to precisely determine energy expenditure and substrate utilization via portable indirect calorimetry across various mobility devices and compare these results to normal ambulation. A main limitation of the findings, as with other simulations, was that the study population consisted of young, healthy volunteers. Future work in a clinical setting with patients is critical to determine if energy expenditure, substrate utilization, pain or exertion, and performance estimates in the current study follow similar trends once injury is present. However, Martin et al[13] suggest that precise and accurate metabolic monitoring in a clinical setting may be impractical; thus, our data do provide a novel contribution to literature at this time. An additional limitation is that were not able to establish a safety profile, risk of falling, or ease of use within the current study design. Given HFC data are relatively limited at this time, further investigations in large

samples in injured patients are needed in order to determine if HFC use can assist with recovery and improvements in quality of life during the nonweightbearing.[20]

Conclusion

The results of this mobility device simulation in healthy adults suggest that HFC and MKS share similar aerobic energy requirements per unit of ambulation time that are below those while using AC. Substrate utilization in HFC was not different than regular walking with a greater reliance on lipid sources for energy. Exertion and pain scores were lower in HFC and MKS than AC. Further research into the physiological benefits of HFC is needed to further establish the potential utility in recovery from lower-extremity injuries.

Ethical Approval

The study was approved by the Institutional Review Board at North Dakota State University. All participants were provided with an explanation of the risks and benefits of the study and written informed consent was obtained before any study procedures were initiated.

Declaration of Conflicting Interests

Funding

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