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Original Research

Comparison of Hip and Low Back Loads between Normal Gait, Axillary Crutch Ambulation and Walking with a Hands-free Crutch in a Healthy Population

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Background

Instead of using axillary crutches, using a hands-free crutch (HFC) has been associated with higher functional outcome scores. However, hip and back pain have been reported as side effects.

Purpose/Hypothesis

The purpose of this study was to compare range of motion and joint reaction forces at the hip and low back between HFC walking, normal walking, and standard crutch walking. It was hypothesized that hip joint reaction forces and low back joint reaction forces would be higher with HFC walking compared with normal walking and axillary crutch walking.

Study Design

Controlled Laboratory Study

Methods

Using 3D motion analysis and force plates, kinematics and ground reaction forces were measured in 12 healthy subjects during gait, crutch ambulation and HFC walking. Gait speed, hip and trunk range of motion, and hip and low back reaction forces, were compared using repeated-measures ANOVA.

Results

Gait speed during HFC ambulation was reduced 33% compared to crutch ambulation ($P<0.001$) and 44% compared to normal gait ($p<0.001$). Hip range of motion was reduced during both crutch conditions compared to gait ($p<0.001$). Trunk range of motion was greatest during HFC walking compared to both gait and crutch ambulation ($p<0.001$). Peak hip joint reaction force during HFC walking was 11% lower than during gait ($p=0.026$) and 30% lower than during crutch walking ($p<0.001$). Peak low back reaction force during HFC walking was 18% higher than during gait ($p=0.032$) but not different than during crutch walking.

Conclusion

Hip joint reaction forces during HFC walking did not exceed those during gait or axillary crutch ambulation. However, a reduction in hip motion using the HFC was associated with increases in trunk motion and low-back loading. These could be a cause for reports of low-back pain accompanying HFC usage.

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Level of Evidence

Level 3

INTRODUCTION

Surgery or injury to the lower extremities may result in a non-weight bearing rehabilitation protocol for a period that may last anywhere between several days to several months. Solutions for mobility such as wheelchairs, crutches and many more, have been in use for many years.[1] Axillary crutches, while being one of the oldest assistive devices, are still one of the most commonly used for partial- or non-weight bearing mobility. While axillary crutches are very simple to use and present an efficient and economical solution, problems with the use of these devices include the inability to use them in case of a concomitant upper extremity injury and the possible development of neuropathies to the brachial plexus after prolonged use.[2–4] As an alternative, the hands-free crutch (HFC) has been designed to mimic the natural gait pattern as best as possible while unloading the shoulders and freeing the patient's hands.

The HFC was initially designed in 1997.[5] The designer sought a way to free the hands while returning to work and day-to-day activities more quickly after a leg injury. Other benefits of this design became apparent as patients with upper extremity injury or disability could utilize this type of crutch. As currently designed, this crutch is only suitable for below-the-knee injuries. However, ability of the lower extremity to attenuate ground reaction forces when wearing the HFC may be reduced, as shock absorption from the ankle and knee joints are effectively eliminated.[6] This may explain reports of hip and back pain while using the HFC.[7]

Many studies have documented the kinetics of axillary crutch ambulation.[3,8–11] However, the primary focus of these studies was on the ground reaction forces on the weightbearing limb and none of these examined the loads at individual joints of the lower extremity or low back. To the authors' knowledge, there have been no studies examining lower extremity kinematics and kinetics while walking with the HFC. The purpose of this study was to compare range of motion and joint reaction forces at the hip and low back between HFC walking, normal walking and standard crutch walking. Due to the reduced ability of the lower extremity to attenuate ground reaction forces while wearing the HFC, it was hypothesized that hip joint reaction forces, as well as low back joint reaction forces, would be higher with HFC walking compared with normal walking and axillary crutch walking.

Figure 1. Locations of reflective markers placed on the lower extremity, trunk and hands-free crutch.

METHODS

Three-dimensional kinematics and ground reaction forces were measured in 12 healthy subjects; 11 men, 1 woman, (age: 36±10 yr, height: 179.0±6.7 cm, weight: 83.1±5.8 kg) during normal gait, axillary crutch ambulation using a swing-through gait pattern and HFC walking (iWalk 2.0, Long Beach, CA, USA). To be included in this study, subjects needed to be free of injury to the lower extremity for at least six months and have no neurological or orthopedic disorders known to affect gait. This study was approved by the Northwell Health Institutional Review Board and prior to participation, all subjects provided informed consent.

Subjects walked at self-selected pace approximately five meters across the lab while a 10-camera motion capture system (BTS Bioengineering, Quincy, MA, USA) recorded kinematic data at 500 Hz. Six force plates (BTS Bioengineering, Quincy, MA, USA) simultaneously recorded ground reaction forces at 1000 Hz. Trials in which the foot did not land completely on the force plates or the subject altered their gait pattern to target the force plate were discarded and the trial was repeated until five successful trials were recorded for each of the three conditions.

Reflective markers were placed bilaterally over the calcaneous, second metatarsal, medial and lateral malleoli, lateral shank, medial and lateral femoral condyles, lateral thigh, greater trochanter, sacrum, anterior superior iliac spines and acromia. During the wearable crutch walking trials, six additional markers were placed on the proximal and distal ends of the HFC (Figure 1). The motion data were then filtered with a fourth-order Butterworth low-pass filter with a cutoff frequency of 6 Hz in order to eliminate any high frequency noise. Sagittal and frontal plane hip and trunk angles, as well as peak vertical ground reaction force (vGRF) and peak hip and low-back joint reaction forces during the stance phase, were calculated using specialized computer software (Visual 3D, C-Motion, Inc., Rockville, MD, USA).

Two-way repeated-measures ANOVA (three conditions by two sides) were used to compare stance phase hip and trunk ranges of motion, peak vGRF, peak hip joint reaction

Table 1. Comparison of hip and low back kinematics (mean±SD) across conditions

	Hands-Free Crutch (HFC)	*Axillary Crutch (AC)*	*Normal Gait (NG)*	*P-value*
Sagittal Hip RoM (deg)	20.6±3.1	29.0±4.8	40.6±6.2	*p < 0.001*†‡*
Frontal Hip RoM (deg)	8.5±1.7	6.9±1.4	11.2±1.8	*p<0.001*‡*
Sagittal Trunk RoM (deg)	10.8±2.7	8.9±2.7	2.4±0.3	*p<0.001*†‡*
Front Trunk RoM (deg)	11.6±2.1	3.7±1.0	3.7±1.4	*p<0.001*†*

* = HFC vs NG; † = HFC vs AC; ‡ = NG vs AC

force and peak low-back reaction force, as well as gait velocity, across conditions (normal gait, crutch gait, HFC gait and side (left vs right). When significant main effects or interactions were found, paired t-tests were used to compare variables measured during each condition. Bonferroni corrections were applied to planned post-hoc comparisons where applicable. Based on gait testing in our lab, we expected to be able to detect a 7% change in peak hip joint reaction force with 80% power at $p<0.05$ using 12 subjects.

RESULTS

Gait speed while wearing the HFC was reduced 33% compared to crutch ambulation (0.8 ±0.5 vs 1.2±0.6 m/s, $P<0.001$) and 44% compared to normal gait (0.8±0.5 vs 1.4±0.5 m/s, $p<0.001$). Frontal and sagittal plane hip range of motion were both significantly reduced during both crutch conditions (axillary and hands-free) compared to normal gait ($p<0.001$, respectively). Trunk range of motion in both the sagittal and frontal planes was greater during stance while wearing the HFC compared to normal gait ($p<0.001$) as well as compared to using the axillary crutch ($p<0.001$) (Table 1).

The highest peak vGRFs were recorded during axillary crutch ambulation ($p<0.05$, respectively, vs. all other conditions). Peak vGRF while wearing the HFC was 30% lower than axillary crutch ambulation ($p<0.001$) and 12% lower than normal gait ($p=0.001$) (Figure 2).

Axillary crutch ambulation also generated the highest peak hip joint reaction forces ($p<0.05$, respectively, vs. all other conditions). Peak hip joint reaction force during HFC walking was 30% lower than during axillary crutch walking ($p<0.001$). Peak low back reaction force during stance on the hand-free crutch was greater than that during normal walking (18% difference, $p=0.032$) but not different from that during axillary crutch walking (1.4% difference $p=1.00$) (Figure 2).

DISCUSSION

As part or their rehabilitation protocol, some patients may be required to be non-weightbearing for anywhere between several days to several months. Developed as an alternative to axillary crutches, the HFC has been designed to mimic the natural gait pattern while unloading the shoulders and freeing the patient's hands. This device may be particularly useful in assisting patients after injuries or surgeries to the foot or ankle. Additionally, the use of this device has been associated with increased activity levels during recovery and rehabilitation and improved outcome scores.[7]

To the authors' knowledge, this is the first study to characterize the kinematics and kinetics of hand-free crutch ambulation and to compare gait biomechanics while walking in this novel assistive device to traditional axillary crutch ambulation and to normal gait. The main purpose of this study was to address the concern that eliminating the shock absorption from both the ankle and the knee on the injured limb may cause greater loads to be transferred to the ipsilateral hip. The results of this study show that peak vertical ground reaction forces and peak hip joint reaction forces were both lower while walking in the HFC compared to axillary crutch gait and normal gait. Therefore, although the ability of the lower extremity to attenuate external forces is reduced, HFC use does not seem to overload the hip.

Additionally, the peak low back reaction force during HFC walking was greater than normal gait but not different than axillary crutch ambulation. In conjunction with this, using the HFC decreased range of motion in the hip, which seems to have been compensated for by a concomitant increase in range of motion of the trunk during stance. The increased low back reaction force combined with the increased trunk range of motion while using this device may contribute to reports of acute low back pain, as observed by Rabani et al.[7]

While there are currently no published data characterizing the kinetics and kinematics of walking in the HFC, the results of the current study comparing axillary crutch ambulation with normal gait compare favorably with the results of Stallard et al. and Goh et al.[3,8] Relative to normal gait, these previous studies observed 24.5% and 21.6% increases in vertical ground reaction forces, respectively, during swing-through crutch ambulation at a similar speed. The current study found no difference in speed between normal gait and crutch ambulation. However, there was a 25% increase in vertical ground reaction force during crutch ambulation. This is most likely due to the increased vertical momentum of the body as it swings through the crutches and lands on lower extremity. By contrast, HFC walking more closely resembles normal gait with no swinging motion and a reduction in ambulation speed. The decrease in vertical motion, as well as ambulation speed, most likely accounts for the reduction in vertical ground reaction force during HFC walking.

There were a few limitations to this study that need to be addressed. First, as gait speed between conditions was

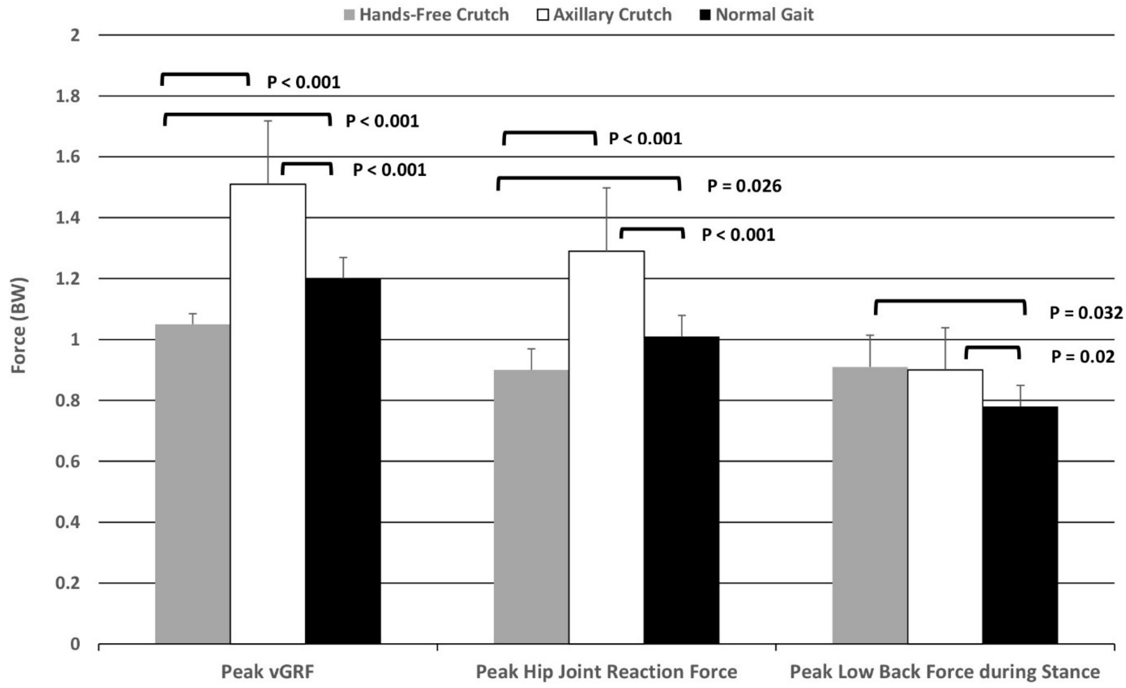

Figure 2. While wearing the hands-free crutch, peak vGRF and peak hip joint reaction forces were significantly lower than axillary crutch ambulation or normal walking. Peak low back reaction force during stance while wearing the hand-free crutch was higher than that during normal walking.

not standardized, the reduction in peak forces while wearing the HFC may have been due to the significant reduction in gait speed compared to the other conditions. Although gait speed has been known to affect ground reaction and joint reaction forces, we chose not to standardize gait speed among conditions due to the fact that patients using these devices will tend to ambulate at speeds that are comfortable and safe for them. Therefore, not standardizing gait speed allows us to assess the biomechanics of ambulating with these devices in a more practical and realistic fashion. However, despite the reduction in gait speed, we still found increases in the low-back force as computed by inverse dynamics. Second, our subjects were given only about half an hour to acclimate to using the HFC. This most likely contributed to the reduced gait speed while walking with this device. With more acclimation time or more habitual use, gait speed, as well as the kinetic variables, may have been more similar to normal gait. Finally, this device was tested on a small population that was predominantly male. Increasing the number of subjects and including more females would give a clearer picture of the effects of the HFC on joint loads during gait.

CONCLUSIONS

The results of this study indicate that although gait speed was significantly affected while wearing the HFC, peak hip joint loads during HFC walking did not exceed those of normal gait or axillary crutch gait. Additionally, lower back reaction force during HFC walking was greater than normal gait but did not exceed that of axillary crutch gait. Therefore, HFC use during rehabilitation and recovery seems to be as safe as using axillary crutches with the added benefit of allowing the patient to use his or her upper extremities. However, the increased range of motion in the lower back may potentially lead to pain or discomfort in this area, and including balance and trunk stability training during the normal course of treatment and also in the initial stages of HFC use may reduce the incidence of pain or discomfort until the patient becomes acclimated to the device.

DECLARATION OF INTERESTS

Stephen J. Nicholas is a paid consultant for Arthrex, Inc.

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