# Biomechanical Analysis of Energy Expenditure by Lower Limbs in Non-Weight Bearing Crutch Ambulation

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## Introduction

Crutch walking kinematics has been an area of interest for trauma surgeons and physical therapists alike, and although it has been studied in the past, its parameters have not been fully described yet. This study aims to compare the energy expenditure of lower limb joints in three commonly used crutch designs (Axillary, Lofstrand, and Platform), in two different gait patterns (swing-to, swing-through) during non-weight bearing ambulation. It was hypothesized that the lowest energy expenditure would be attained by using a swing-through gait and the axillary crutch design.

## Methods

This study was approved by the Internal Review Board (IRB). A total of ten healthy volunteer students (5 females, 5 males) participated in the study. All volunteers were above the age of 18 and instructed on proper use of the crutches by a study personnel before testing; ViconNexus® Motion capturing system (Vicon Motion Systems, Inc., Oxford, England), integrating ten MCam cameras (Vicon Motion Systems, Inc., Oxford, England) and four Kistler® force plates (Kistley Instrumente AGm Winterthurm, Switzerland), recorded the force acting on the major lower limb joints. Anterior-posterior, medial-lateral, and axial compression forces were calculated throughout the gait cycle and normalized to body weight. The energy expenditure was quantified as the impulse (i.e., integral of the force during a gait cycle - figure 1) for each joint of the lower limbs (i.e., hip, knee, and ankle). Differences in energy expenditure due to gait type were investigated via paired Student's t-test separately for each joint and crutch design. Also, for each gait type, the effect of crutch design was investigated via ANOVA test for each joint separately. For each test, the level of significance was set to 95%.

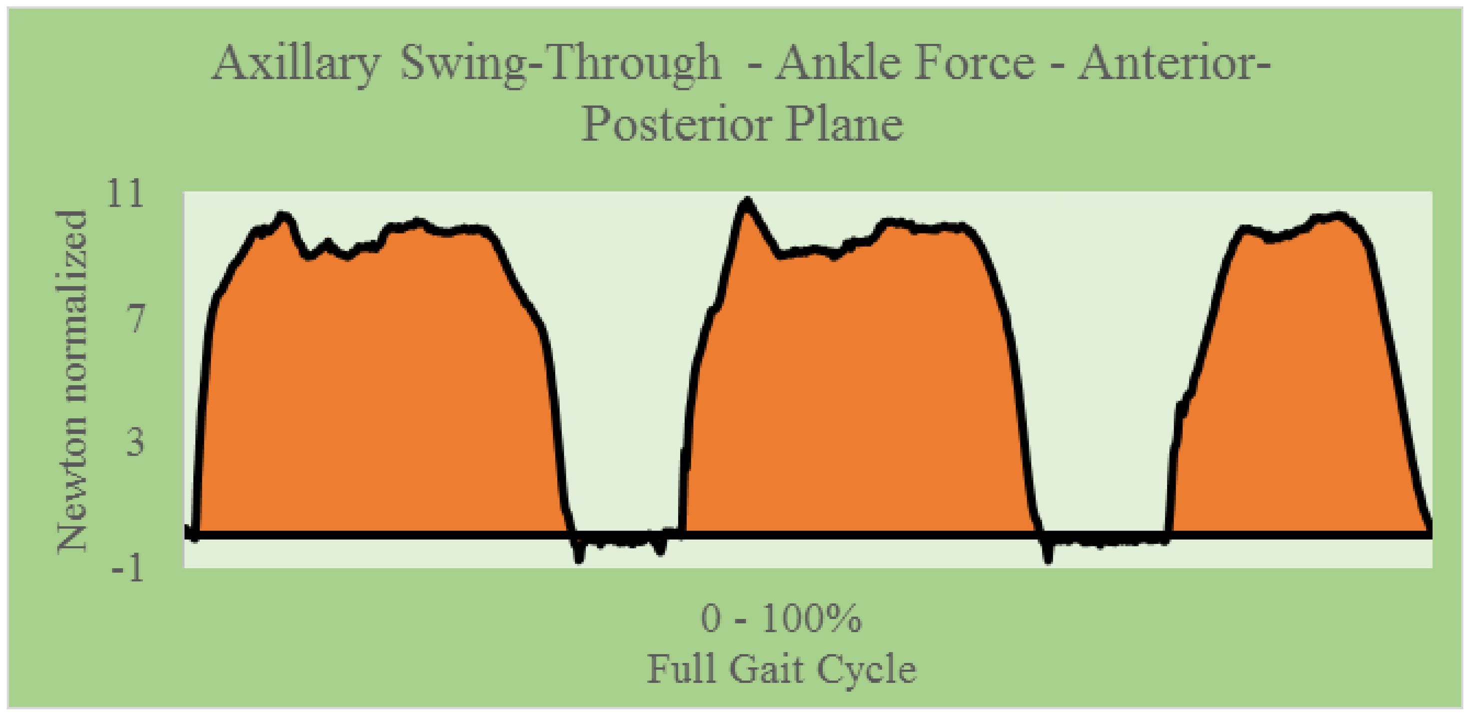


Figure 1: An example of three gait cycles calculated for one subject. Represented in orange is the impulse for the gait cycle in Kg*m/S.

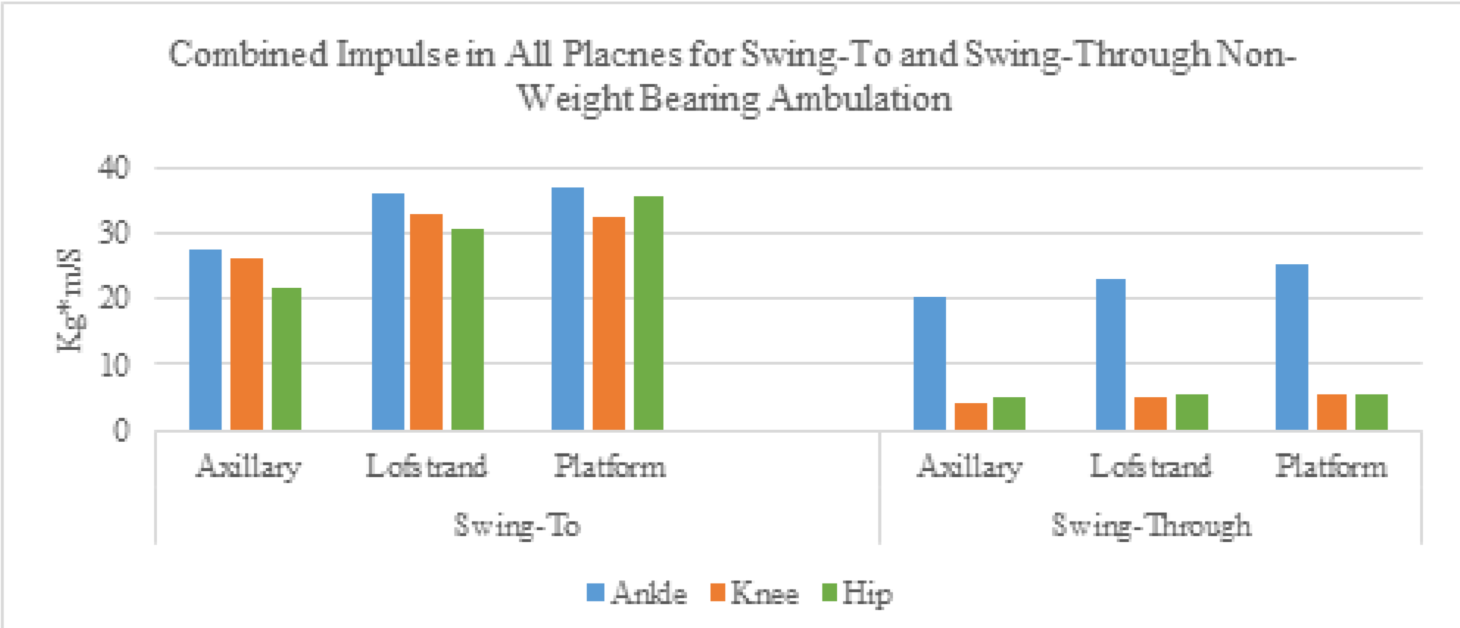


Figure 2: Combined impulse values were calculated, by taking the square root of the sum of the squares of the three planes, and reported above. Swing-through gait shows high impulses combined impulse on the ankle joint.

## Significance

This study provides guidelines for surgeons and physical therapists to make an informed decision on what gait type and which crutch to use for their trauma patients.

| | | Ankle | | | Knee | | | Hip | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Gait Type** | Crutch Type | Anterior-Posterior | Medial-Lateral | Axial Compression | Anterior-Posterior | Medial-Lateral | Axial Compression | Anterior-Posterior | Medial-Lateral | Axial Compression |
| **Swing-To** | Axillary | 27.21 | 3.72 | 1.48 | 3.58 | 4.39 | 25.53 | 1.96 | 2.83 | 21.14 |
| | Lofstrand | 35.76 | 3.84 | 3.4 | 5.89 | 5.34 | 32.03 | 2.13 | 4.28 | 30.15 |
| | Platform | 36.5 | 4.48 | 2.56 | 6.41 | 5.1 | 31.11 | 2.38 | 4.24 | 35.29 |
| | | | | | | | | | | |
| **Swing-Through** | Axillary | 20.21 | 2.46 | 1.75 | 2.85 | 3.54 | 20.65 | 1.51 | 2.65 | 16.01 |
| | Lofstrand | 22.74 | 2.38 | 2.08 | 3.61 | 3.25 | 20.03 | 1.58 | 2.61 | 18.85 |
| | Platform | 24.67 | 2.94 | 2.62 | 3.77 | 3.03 | 19.94 | 1.6 | 3.23 | 25.4 |

Table 1: Average impulse values in swing-to and swing-through gaits for lower limb joints reported in Kg*m/s

## Results

Swing-to gait showed significantly higher impulses than swing-through gait in all force directions on all joints in the Lofstrand crutch ($p<0.001$). The same can be said about the platform crutch with the exception of the axial compression impulse on the ankle joint where it showed no statistical significance. The axillary crutch behaved differently showing no significant differences between swing-to and swing-through gait in the anterior-posterior and lateral-medial impulses on the hip joint, and it resulted in an opposite result with swing-through gait generating significantly higher axial compression impulse on the ankle joint. Other comparisons followed the same pattern of significance of lofstrand and platform crutches with the swing-to gait showing higher impulses.
Comparing impulses on one joint between different crutch types within the same gait showed significantly lower axial compression impulses on the hip joint in swing-to gait when comparing the axillary crutch to the other two designs ($p<0.05$). The same result was found in the swing-through gait axillary crutch design to lofstrand crutch hip joint comparison ($p<0.05$), but no significance was found when the comparison was made to the platform crutch. The ankle joint in swing-to gait showed the same pattern, of significantly lower axial compression impulses, as the hip joint showed when using the an axillary crutch ($p<0.05$). All other comparisons showed no significant results. A summary of the results is shown in (table 1).

## Discussion

The impulse represents the force on a joint during a specified time period, in this instance a full gait cycle. Therefore, a lower impulse generated by a joint means lower energy expenditure by the limb to complete one gait cycle. The hypotheses of lower impulses on joints when using a swing-through crutch held true for the lofstrand crutch. And it was mostly true for the other two crutch designs (except for hip and ankle joints in the axillary crutch and the ankle joint in the platform crutch). This is probably because in swing-to gait the patient will have to stop the gait momentum mid swing resulting in high enough forces to cause significant differences in impulses in what otherwise is a shorter gait. When looking at each gait type separately and compare the exerted impulse by the three crutches on the same joint within that gait type, the authors hypothesized that the most familiar crutch design (axillary crutch) would result in lower impulses when compared to the other two crutch designs. This was true for axial compression impulses in the swing-to gait on the hip and ankle joints. Similar results were found for the hip joint in swing-through gait when comparing the axillary crutch to the platform design.
In summary, this study demonstrates that when given a choice between crutches and gait type, the best option for least energy expenditure by the lower limb non-weight bearing ambulation will be achieved by using a lofstrand crutch in swing-through gait. Also, if a swing-to gait must be used, the axillary crutch design shows the best results.