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Lower extremity kinematics and kinetics during level walking and stair climbing in subjects with triple arthrodesis or subtalar fusion

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Abstract

The purpose of this study was to identify the kinematic and kinetic strategies used by patients with unilateral triple arthrodesis or subtalar fusion during level walking, stair ascent, stair descent and to determine the influence of these different conditions on kinematics and kinetics. Nine subjects with unilateral triple or subtalar fusion and five normal control subjects were recruited for this experiment. Temporal distance, kinematic and kinetic data were collected using a six camera 3-D motion analysis system and a custom fabricated set of stairs with five steps; the second and third steps were each instrumented with one force platform. During level walking, affected limbs lost all of the plantarflexion at the ankle joint during push-off and showed greater knee flexion angle during the same period of stance. During stair ascent, affected limbs showed a different movement pattern at the knee, a greater knee flexion angle during the whole stance phase and a near zero degree of plantarflexion angle during the forward continuance (FCN) phase. During descent, affected limbs showed a greater knee flexion angle during the whole stance phase and less ankle dorsiflexion angle during the same period of stance phase. At the ankle, peak moment and power values were significantly different between the affected side and the limbs of the control subjects during level walking in the push-off phase, stair ascent in the FCN phase, and stair descent in the weight acceptance (WA) phase, where the affected limbs had a lower plantarflexion moment and power values.

Keywords: Triple arthrodesis; Stair climbing; Gait

1. Introduction

Triple arthrodesis is a procedure that fuses the subtalar joint, talonavicular joint, and calcaneocuboid joint. It is a useful operation for the relief of chronic pain and treatment of instability and deformity in the rearfoot. The clinical results of triple arthrodesis have been reported in several long-term studies; in general, these have been found to be favorable, although the development of radiological evidence of tibiotalar arthritis has been of concern [1–8]. Subtalar arthrodesis is a procedure that fuses only the subtalar joint and is performed mostly for the treatment of isolated subtalar arthrosis. In biomechanical studies, fusion of the subtalar joint not only limits the subtalar motion but also decreases the motion of the talonavicular joint and calcaneocuboid joint. Therefore, the gait pattern after subtalar fusion is very similar to the gait pattern after triple arthrodesis [9,10].

Ambulation on stairs is an important aspect of daily activities for many patients with triple arthrodesis; however, little is known about the kinematic and kinetic strategies that are used to accomplish this task. During stair ascent, the lower limb functions not only to support and balance body weight, but also raise that weight onto the supporting step. For patients with triple arthrodesis who use a reciprocal gait pattern, the primary responsibility for raising this weight on the affected side must be divided between the knee and hip, with the potential for some additional help from the unaffected

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side during periods of double support. The foot segment with arthrodesis probably has a minimal contribution to the lower-limb energy. A number of studies have investigated kinetics during normal stair ambulation [11–13]. McFadyen and Winter [12] partitioned the stance phases of stair ascent into three parts: weight acceptance (WA), pull-up (PU), and forward continuance (FCN); the swing phases into two parts: foot clearance (FCL) and foot placement (FP). The stance phase whilst walking down stairs was broken down into three sub-phases described as WA, FCN and controlled lowering (CL). The swing period had two phases again, including leg pull-through (LP) and preparation for FP. Similar divisions for ascent and descent phases were adopted in this study. The patterns for normal stair climbing show the dominant role of the knee during WA and PU, with supporting roles played by the hip and ankle. During FCN, the ankle has the major role, with relatively little contribution occurring from the knee and hip.

We believed that a kinetic analysis would allow for the assessment of the underlying strategy that distinguishes between the lower limbs of triple arthrodesis subjects. Knowledge of the moments and powers could be used to explain how the work is distributed among the different joints, thereby enabling a more complete understanding of level walking or stair ambulation after triple arthrodesis.

Beischer et al. [14] in their follow-up study of patients who had had triple arthrodesis, noted that abnormal moments and power generation at the ankle and decreased angular range of motion in the ankle and increased angular range of motion in ipsilateral knee joints were associated with triple arthrodesis. While information for level walking is available [14], data on the high demand activities of stair ascent and descent, after triple arthrodesis or subtalar fusion, remain to be documented. The purpose of the present research was to identify the kinematic and kinetic strategies used by patients with unilateral triple arthrodesis or subtalar fusion during level walking, stair ascent, stair descent and to determine the influence of these different conditions on kinematics and kinetics.

2. Method

2.1. Subjects

Informed consent was obtained from nine subjects with unilateral arthrodesis, including two right and seven left, triple arthrodesis or subtalar fusions who participated in the study (Table 1). They had a mean age of 44.33 ± 14.28 years (range from 27 to 65 years). The mean duration since operation was 40.22 ± 19.34 months. There was no history of neurological impairment. The pre-operative diagnosis necessitating triple arthrodesis or subtalar fusion was post-traumatic osteoarthritis (3 ft) and congenital cavovarus deformity (6 ft). All could ascend and descend the stairs without support. A group of five normal control subjects also participated in the present study. Their mean age was 31.6 years (range 23–37 years), mean mass 67.6 kg (range 51–76 kg), and mean height 168 cm (158–178 cm).

2.2. Equipment

We performed analysis of the motion of the lower limbs by using passive light reflecting markers (ExpertVision System, Motion Analysis Corp., CA) and force assessment using two floor mounted force plates (Kistler Instrument Corp., Switzerland). Marker coordinate data was collected online at 60 Hz. Two Kistler force plates were used to collect the three-dimensional force data at a sampling frequency of 1000 Hz while the subject was walking barefoot. Ground reaction forces of multiple trials were collected synchronously with motion analysis. Kinetics were obtained by combining the outputs from the force-plates with the outputs from the motion analysis system.

2.3. Stair design

A wooden stair was created by the use of five non-connected wooden sections, as shown in Fig. 1. The second and third sections of the stair were placed on force plates for kinetic

Table 1
The length of the follow up, the age of the patient, type of surgery performed, and anthropometric data in nine patients treated with a triple arthrodesis or subtalar fusion

Case no.	Age (years)	Gender	Height (cm)	Weight (kg)	Duration after surgery (months)	Etiology	Surgical type	Affected side
1	59	Female	160	79	41	Congenital foot deformity	Triple arthodesis	Left
2	23	Male	168	63	30	Congenital foot deformity	Triple arthodesis	Left
3	58	Female	155	83	18	Congenital foot deformity	Triple arthodesis	Left
4	27	Male	174	79	42	Post-trauma	Triple arthodesis	Left
5	42	Female	159	78	54	Post-trauma	Triple arthodesis	Right
6	43	Female	157	65	40	Congenital foot deformity	Subtalar fusion	Left
7	44	Female	158	50	78	Congenital foot deformity	Triple arthodesis	Left
8	65	Male	160	88	13	Post-trauma	Subtalar fusion	Right
9	38	Male	164	66	46	Congenital foot deformity	Triple arthodesis	Left
Average	44.33		161.667	72.33	40.22			
S.D.	14.28		6.02	12.04	19.34			