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Lower Extremity Kinematic Profile of Gait of Patients After Ankle Fracture: A Case-Control Study

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ABSTRACT

The present study examined the differences in the lower extremity gait kinematic profile of patients recovering from ankle fracture compared with healthy controls. In addition, we inquired whether the profile would differ among fracture severity groups. A total of 48 patients participated in the present prospective, case-control study. The gait of 24 patients recovering from an ankle fracture injury and 24 healthy matched controls was examined using an inertial measurement unit sensor system. The following gait parameters were evaluated: knee range of motion (ROM) during the swing phase, maximum knee flexion angle during stance, thigh and calf ROM, and stride duration. Statistically significant differences were found between the ankle fracture group and the control group for all parameters. The patients with ankle fracture had a lower knee ROM during swing phase compared with the control group (mean ± standard deviation 43.0° ± 15.5° compared with 66.7° ± 5.1°, respectively; $p < .001$). The maximum knee flexion angle during stance was lower in the patients with ankle fracture than in the control group (mean ± standard deviation 10.5° ± 6.1° compared with 21.2° ± 4.5°, respectively; $p < .001$). Patients with ankle fracture also had lower gait cycle thigh and calf ROM angles ($p < .001$) and a longer stride duration ($p < .001$) compared with the control group. No statistically significant differences were found among the severity groups. These results suggest that the gait kinematic characteristics vary between healthy people and patients recovering from an ankle fracture injury during the short-term period after injury.

The ankle joint complex is of great importance in normal ambulation, daily activities, and sports. Ankle fracture is one of the most common injuries of the lower limb (1) and the incidence of ankle fracture injuries has increased in the recent decades (2–4). Thus, research to further understand how an ankle fracture affects the gait is becoming more relevant.

People with an ankle fracture injury often experience pain, stiffness, weakness, swelling, and limitations in activities such as stair climbing and walking (5). This can last for ≤2 years after injury (1). Comprehensive research of gait analysis has been performed in patients who have undergone procedures such as ankle fusion and total ankle replacement, patients with ankle and tibial stress fractures, and patients with ankle sprains. This is not the case for ankle fractures, and lower limb motion abnormalities expressed in ankle or knee range of motion (ROM) during gait have not been commonly investigated (6–9).

The portable walkway is a simplified method to study spatiotemporal parameters. It saves the high costs and logistic efforts inflicted by the usually used dedicated gait laboratory. A recent case-control study used a portable walkway to provide information on the spatiotemporal characteristics of gait and found compromised gait patterns and limb symmetry in patients after an ankle fracture injury compared with the controls (10). Nevertheless, portable walkway systems cannot be used to measure joint motion or kinetics, which can add information and reflect the patient's condition. Recent studies have shown that inertial measurement units are accurate and reproducible in the measurement of joint and limb segment ROM in the assessment of gait in aging patients (11) and in knee osteoarthritis (12). Inertial measurement units are comparatively easy to use, requiring no specialist facilities, and have the potential to be used within a busy clinic or rehabilitation unit (13).

Several studies have examined the feasibility of using a severity fracture classification system as a consistent predictor of the surgery

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functional outcomes. The results, however, have been conflicting (10,14–16). Most used self-assessment questionnaires and functional scores to evaluate the functional status of patients after ankle fracture surgery. Questionnaires are considered a valid method of assessment; however, they are subjective. In contrast, objective methods of evaluation can provide a clear benchmark. A recent study has shown that patients with a unimalleolar fracture constitute a different group with significantly better gait patterns and clinical symptoms compared with those with bimalleolar and trimalleolar fractures. Furthermore, it seems that bimalleolar and trimalleolar fractures affect the gait pattern and clinical symptoms similarly, at least in the short term (10).

The purpose of the present study was to compare the lower limb gait kinematics between patients with an ankle fracture injury and healthy controls. We hypothesized that differences between these 2 groups exist, and we sought to quantify them. Additionally, we examined the possible linkage between ankle fracture severity classifications and postoperative functional outcomes. We hypothesized that a more affected gait profile would be present in patients with a more severe fracture classification. Therefore, we conducted a case-control study to evaluate and compare the gait profile of these 2 populations.

Patients and Methods

The present study was a part of a larger randomized control trial examining the effect of a biomechanical therapy on the clinical outcomes, function, and gait pattern of patients after an ankle fracture. The institutional Helsinki committee provided ethical approval.

A total of 24 patients with an ankle fracture injury were referred to the study by orthopedic surgeons (B.K., M.N., E.P.) from a leading medical center from December 2011 to August 2014. All patients underwent surgery using open reduction and internal fixation. The referred patients with ankle fracture had short-term data available after injury. The inclusion criteria were unimalleolar, bimalleolar, or trimalleolar fracture and $\leq$6 weeks' time from weightbearing approval. The exclusion criteria were an injury in addition to the ankle fracture, other musculoskeletal disorders or neurologic problems, and any condition that would prevent the patient from performing a gait analysis test. We included 24 healthy people as the control group. These people were recruited from the Royal National Orthopedic Hospital (London, UK). Both the patients and the healthy volunteers provided written informed consent.

Measuring System

The system used in the present trial comprised 4 sensor modules, a laptop computer, and 4 straps (GaitSmart, London, UK). The inertial measurement units contain 3 orthogonal gyroscopes and 3 orthogonal accelerometers, described in a previous study of joint angles by Cooper et al (17). The sensors contain a precision clock and a memory storage device card, and the data are gathered from each sensor at 102.4 Hz.

The 4 sensors were time stamped and synchronized using the Poseidon software on the laptop computer. The sensors were then disconnected from the laptop computer. Each person was asked to stand while the straps were placed on the thigh and calf of each leg. The location of the straps on the calf was at the level of the belly of the gastrocnemius muscle, with the sensor located on the lateral side of the calf. The location of the straps on the thigh was at the proximal end of the thigh, just below the greater trochanter, with the sensors located on the lateral side of the thigh. Next, all the sensors were switched on, and the patient was asked to walk steadily for $\geq$7 strides, approximately 8 m.

The analysis of the data was performed using the Poseidon software installed on the laptop computer. The software was used to calculate the typical stride for level walking (i.e., the stride with lowest error to all other strides) (18). The following parameters were evaluated: knee ROM during swing phase, maximum knee flexion angle during the stance phase, and thigh and calf ROM during 1 gait cycle (all in degrees). These parameters were collected for both limbs. The mean stride duration in seconds was measured for each patient. The symmetry between limbs for each parameter (except for stride duration) was calculated for both the control group and the ankle fracture group. All measurements were performed by 2 investigators (D.B., M.K.M.).

Statistical Analysis

All statistical analysis was performed by an independent biostatistician. The data were analyzed using SPSS software, version 21.0 (IBM Corp., Armonk, NY), and the significance level was set at $p \leq .05$. Nonparametric 1-sample Kolmogorov-Smirnov tests were calculated to compare the observed cumulative distribution function for the continuous variables with the normal theoretical distribution. Group differences for age and body mass index were assessed using Student's *t* test. Group differences for age were also analyzed using one-way analysis of variance to examine the fracture type subgroups (unimalleolar, bimalleolar, and trimalleolar) and healthy control groups. The interrelationships between gender and control and patient groups were examined using contingency tables. Differences between the control and patient groups for gait characteristics were analyzed using the Excel Student *t* test and the Mann-Whitney *U* test. Differences between the control and different fracture subtype groups were analyzed using the Kruskal-Wallis test and Mann-Whitney *U* test for each pair of groups.

Results

A total of 24 patients (14 females [58%] and 10 males [42%]) with an ankle fracture injury participated in the present study. The mean $\pm$ standard deviation (SD) age of the patient group was 48.8 $\pm$ 12.8 years, and their mean $\pm$ SD body mass index (BMI) was 27.5 $\pm$ 3.8 kg/m^2. A total of 24 healthy people (14 females [58%] and 10 males [42%]) served as the control group. Their mean $\pm$ SD age was 48.9 $\pm$ 12.6 years, and their mean $\pm$ SD BMI was 26.2 $\pm$ 2.9 kg/m^2. No statistically significant differences in age or BMI were present between the patients recovering from an ankle fracture and the healthy controls ($p = .982$ for age and $p = .214$ for BMI). This was confirmed by the Mann-Whitney *U* test results ($p = .951$ for age and $p = .208$ for BMI).

The results from the one-way analysis of variance showed no statistically significant group differences for age between the ankle fracture severity subgroups (unimalleolar, bimalleolar, and trimalleolar) and healthy control group ($p = .626$). Furthermore, no statistically significant differences were present in the gender distribution between all groups, including the fracture severity subgroups ($p > .05$). These findings suggest that gender, age, and BMI were not confounding factors to the results of the present study.

The results from Student's *t* test showed statistically significant differences between the ankle fracture and control groups for knee ROM during swing phase, maximum knee flexion angle during stance, thigh and calf ROM through a single gait cycle, and stride duration. The results from the nonparametric Mann-Whitney *U* test confirmed statistically significant differences between the patient and control groups for all of these parameters (Fig. 1; $p \leq .05$ for all).

The different fracture severity subgroups (classified as unimalleolar, bimalleolar, and trimalleolar fractures) were also examined using statistical analysis. Statistically significant differences between each fracture severity subgroup and the healthy control group were found in the swing phase knee ROM, maximum knee flexion angle during stance, and the thigh and calf ROM through a single gait cycle parameter in both the involved and the uninvolved limbs, as well as in the stride duration parameter. The results from the nonparametric Mann-Whitney *U* test for each pair of groups confirmed no statistically significant differences among the different fracture type groups (Table).

The symmetry between the limbs for each parameter was calculated for both the control group and the patients with an ankle fracture. A statistically significant difference was found between the involved and uninvolved limb for calf ROM during the gait cycle ($p \leq .001$; Fig. 2). No statistically significant symmetry differences were found in any of the other measurements.

Considering each ankle severity group, only the bimalleolar fracture group presented with differences in symmetry for 2 parameters. The mean $\pm$ SD swing phase knee ROM was 42.2° $\pm$ 18.6° in the involved limb compared with 49.3° $\pm$ 9.7° in the uninvolved limb, and the mean $\pm$ SD calf ROM was 51.3° $\pm$ 20.1° for the involved ankle and 58.2° $\pm$ 12.6° for the uninvolved ankle ($p \leq .001$).

Discussion

The present study sought to characterize the gait patterns of patients recovering from an ankle fracture injury by joint movement measurement using an inertial measurement unit sensor system and