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One year follow-up after operative ankle fractures: A prospective gait analysis study with a multi-segment foot model

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ABSTRACT

Ankle fractures are one of the most common lower limb traumas. Several studies reported short- and long-term post-operative results, mainly determined by radiographic and subjective functional evaluations. Three-dimensional gait analysis with a multi-segment foot model was used in the current study to quantify the inter-segment foot motions in 18 patients 1 year after surgically treated ankle fractures. Data were compared to that from gender- and age-matched healthy controls. The correlations between Olerud/Molander ankle score and kinematics were also evaluated. Patients with ankle fractures showed less plantarflexion and smaller range of motion in the injured talocrural joint, which were believed to be a sign of residual joint stiffness after surgery and immobilization. Moreover, the forefoot segment had smaller sagittal and transverse ranges of motion, less plantarflexion and the hallux segment had less dorsiflexion and smaller sagittal range of motion. The deviations found in the forefoot segment may contribute to the compensation mechanisms of the injured ankle joint. Findings of our study show that gait analysis with a multi-segment foot model provides a quantitative and objective way to perform the dynamic assessment of post-operative ankle fractures, and makes it possible to better understand not only how the injured joint is affected, but also the surrounding joints.

1. Introduction

Fractures of the ankle joint are one of the most common intra-articular injuries of the lower extremity, probably due to the high forces it withstands and the mass it supports [1]. Several investigators have reported short- and long-term results after surgery. However, radiographic assessment and subjective functional evaluations have been the main instruments to determine the results [2,3,4].

The human foot, the only body segment that acts on an external surface in upright, unsupported positions, supports and balances the body during gait. Ankle injuries, foot pain and dysfunction may affect its ability to cope with uneven ground and maintain dynamic stability [5]. Dynamic foot and ankle motion has been studied using mathematical modeling [6] and cadaveric specimen measurements [7]. Techniques for objective evaluation of gait have been utilized in assessment of patients with cerebral palsy [8], myelomeningocele [9], and rheumatoid arthritis [10], among others. Three-dimensional gait analysis provides objective information about gait changes, which may help document disease progression or improvement [11]. However, the conventional gait model representing the foot as a single segment with a revolute ankle joint can only document the ankle motion in the sagittal plane, which is not adequate to describe complex three-dimensional foot motion [12]. During the last few years, various multi-segment foot models have been developed and applied to describe normal and pathological gait [13,14,15].

Few gait studies have focused on ankle fractures. Lower walking velocity, decreased stride length and reduction of the internal dorsiflexion moment in the injured ankle joint immediately following heel contact were observed in a 1-year surgical treatment follow-up study [16]. Although gait asymmetry was found in a plantar pressure distribution study, no control subjects with perfect symmetry were found either [17]. It was believed that most compensation mechanisms for the hindfoot probably occur in the forefoot [17].

The aim of the present study was to quantify foot motion changes in patients with ankle fractures 1 year after open reduction and internal fixation (ORIF) and compare those findings with a matched control group. The specific aims were to determine whether:

(1) The injury resulted in a decreased range of motion (ROM) at or around the injured area.

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(2) Motion between other segments in either limb was affected by the unilateral ankle fractures, i.e. whether secondary restriction or increase of motion exists. Since these secondary effects are unknown, complete kinematics between all segments (tibia, hindfoot, forefoot, and hallux) are presented.

(3) The ankle functional outcomes measured by Olerud/Molander ankle score (OMAS) were associated with altered kinematics observations [18].

2. Methods

2.1. Subject

Eighteen patients with unilateral ankle fractures who were treated with ORIF at the Department of Orthopaedic Surgery at Karolinska Institutet University Hospital November 2005 to December 2006, were invited to participate in a follow-up study using clinical gait analysis including a multi-segment foot model at least 1 year post-operatively. All patients were selected on the basis of availability and willingness to participate. Twelve patients had a lateral malleolar fracture and six had a trimalleolar fracture. One patient with a lateral malleolar fracture had suffered an infection that required oral antibiotics and revision surgery. The median age (range) of the 18 ankle fracture patients was 39 (17–64) years and 10 were male. The average height and body weight were 173 cm and 76 kg. The mean (S.D.) follow-up time was 13 (3) months post-operatively. An age- (median: 40, range: 19–64 years) and gender-matched control group (average height: 172 cm and body weight: 72 kg) was gathered from a cohort of healthy adults without musculoskeletal disease or history of lower-extremity injury. Ethical approval for this study was obtained. All subjects participated with written informed consent.

2.2. Treatment methods

All patients received the department's standardized treatment. Severely dislocated fractures were adequately reduced on admission and immobilized in a semicircular cast. General indication for surgery was incongruity of the ankle joint and/or displacement of >2 mm in any plane on the X-ray. ORIF according to the AO principle [19] was performed. Transfixation of the syndesmosis was performed in all type C fractures[1] or if pathological movement was found at intraoperative testing. Post-operatively, the ankle was elevated and immobilized in a semicircular cast for 1–2 days, then in a circular cast. Partial or full weight bearing on crutches was allowed and instructed by a physiotherapist. All patients were examined two and six weeks after surgery with regards to wound healing and function. After six weeks the external fixation was terminated and the patients were again instructed by a physiotherapist concerning movement and weight bearing. All patients received a written training program and were offered further training in an ankle fracture group. The patients were evaluated by a physiotherapist 6 and 12 months post-operatively and the OMAS was recorded. The OMAS is a self-reported functional outcome score, designed for evaluating symptoms after ankle fractures. The score includes nine questions regarding pain, stiffness, swelling, stair-climbing, running, jumping, squatting, supports and activities of daily life. It ranges from 0 (totally impaired) to 100 (completely unimpaired)[18].

2.3. Multi-segment foot model

A modified version of the Oxford Foot Model (Stebbins et al. [14]) was used in the study. The model simplified complex anatomical foot structure to three rigid segments (tibia, hindfoot, and forefoot) and one vector (hallux). The midfoot was regarded as a mechanism transmitting motion between the hindfoot and forefoot. All inter-segment motions except hallux motion were three-dimensional. Euler angles were calculated for inter-segment rotation following the sequence of Grood and Suntay (flexion, adduction, and rotation) [21]. The following motions were determined: hindfoot relative to tibia (Hindfoot/Tibia), forefoot relative to hindfoot (Forefoot/Hindfoot), forefoot relative to tibia (Forefoot/Tibia), and hallux relative to forefoot (Hallux/Forefoot).

Since metatarsophalangeal joints were of interest, a modified method based on a spherical rotation coordinate system [22] was created to obtain frontal hallux joint rotation (varus/valgus) relative to the forefoot. A unit vector was used to represent the long axis of the hallux segment and the rotation was determined in a reference coordinate system which was assumed to be fixed to and aligned with the forefoot segment. Thus Hallux/Forefoot varus/valgus can be measured as an angle between the unit vector of the hallux and its projection on the sagittal plane of the forefoot.

2.4. Gait analysis

All patients walked barefoot along a 10 m walkway at a self-selected speed. 3D gait analysis with an 8-camera motion system (Vicon MX 40, Oxford, UK) was performed. A set of 36 markers (9 mm) was placed bilaterally on bony landmarks to model the tibia, hindfoot, forefoot and hallux based on the multi-segment foot model (Stebbins et al. [14]). Series of barefoot walking trials were collected to achieve three left and three right trials yielding complete data sets for each subject. Discrete kinematics and temporal-spatial parameters were calculated for each gait cycle, and the averages from the three left and three right gait cycles were used for further analysis.

2.5. Statistics analysis

Data (inter-segment foot kinematics and temporal-spatial parameters) were analyzed initially using a two-way repeated measures ANOVA with side (injured side or non-injured side) as the within-group factor and group (ankle fractures or control group) as the between-group factors. Right and left side data from the control group were randomized and matched to the fracture group's injured and non-injured sides, to eliminate possible bias due to a dominant side. If a significant interaction ($p \leq 0.05$) was found between factors, simple main effects tests were performed, i.e. effects of one factor holding the other factor fixed. One procedure, suggested by Kirk [23], to correct the error rate for these tests is to assign the same error rate to the collection of tests as that allotted to the "family". The simple main effects sums of squares represent a partition of families (just as many as the number of effects in the model). Therefore the overall error rate is 0.05 times the number of "families". The Bonferroni procedure can then be used for the simple tests (the overall error rate divided by the number of simple main effects tests). For our analysis, each simple main effects F-statistic was evaluated at the 0.15/4 = 0.0375 level of significance [23]. The Spearman's rank correlation coefficient was used to identify associations between OMAS and inter-segment foot kinematics parameters.

3. Results

3.1. Kinematics

3.1.1. Hindfoot/Tibia motion

A group-side interaction was determined in the Hindfoot/Tibia peak plantarflexion in both the stance ($p = 0.048$) and swing phases ($p < 0.001$), and sagittal ROM ($p < 0.001$) in the swing phase (Fig. 1, Table 1). In the fracture group, the injured side was less plantarflexed ($p = 0.003$) and showed less ROM ($p = 0.002$) in the swing phase than the non-injured side. No significant differences were found in the frontal or transverse planes.

3.1.2. Forefoot/Hindfoot motion

A group-side interaction was determined in the Forefoot/Hindfoot transverse ROM in both stance ($p = 0.050$, Fig. 1, Table 2) and swing phase ($p = 0.001$), where the injured side showed less ROM than both the non-injured side (stance: $p = 0.020$, swing: $p = 0.007$) and control (swing: $p = 0.021$). No significant differences were found in the sagittal and frontal plane.

3.1.3. Forefoot/Tibia motion

A group-side interaction was determined in the Forefoot/Tibia peak plantarflexion ($p < 0.001$), sagittal ROM ($p<0.001$), peak adduction ($p = 0.040$), and transverse ROM ($p = 0.013$) in the swing phase (Fig. 1, Table 3). Compared to the non-injured side and to controls, the injured side showed less plantarflexion ($p = 0.001$, $p = 0.037$). Compared to the non-injured side, the injured side showed less adduction ($p = 0.030$), and smaller ROM in the sagittal ($p < 0.001$) and transverse planes ($p = 0.030$). No significant differences were found in the frontal plane.

3.1.4. Hallux/Forefoot motion

A group-side interaction was determined in the Hallux/Forefoot peak dorsiflexion ($p = 0.021$) and sagittal ROM ($p = 0.010$) in the swing phase, peak varus ($p = 0.020$), peak valgus ($p = 0.031$) and average varus ($p = 0.019$) in the stance phase (Fig. 1, Table 4). Compared to the non-injured side, in the sagittal plane, the injured side was less dorsiflexed ($p = 0.011$) and had a lower ROM ($p = 0.005$) in the swing phase. Compared to the control, the non-injured side showed a higher ROM ($p = 0.012$) in the sagittal plane in the swing phase, and a higher peak and average varus angle ($p = 0.003$, $p = 0.020$) in the stance phase.

[1] Weber type C fractures [20] (fibular fracture above the level of syndesmosis).