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Comparison of Spatiotemporal Gait Parameters Following Operative Treatment of Trimalleolar Ankle Fractures vs Healthy Controls

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Abstract

Background: Controversy continues regarding appropriate indications for posterior malleolus fracture fixation in unstable rotational trimalleolar ankle injuries, with limited data comparing gait in operatively treated trimalleolar ankle fractures vs control populations. The purpose of this study was to evaluate the effect of trimalleolar ankle fracture fixation on gait parameters in the early postoperative period as compared to a healthy control population.

Methods: Adult patients having undergone operative treatment of isolated trimalleolar ankle fractures were eligible for inclusion. A total of 10 patients met the inclusion criteria and participated in the analysis. Patients were evaluated using standard parameters of human gait 6 months after their index procedures, with gait values compared to a population of 17 non–age-matched healthy control subjects in addition to literature values of healthy populations of younger and older subjects.

Results: Significant differences were noted between the spatiotemporal gait parameters of healthy control subjects and patients who had undergone operative treatment of trimalleolar ankle fractures. However, within the fracture group itself, no differences were found between patients with or without posterior malleolar fixation for any of the tested gait parameters. When patients were compared to literature values of younger and older healthy control populations, they were found to have gait patterns more similar to older rather than younger individuals.

Conclusion: Operative fixation of trimalleolar ankle fracture does not restore normal gait function in the early postoperative period. Fixation of the posterior malleolus in particular also does not appear to improve gait characteristics. Patients who undergo surgery for these injuries demonstrate gait patterns similar to those of healthy older adults.

Level of Evidence: Level II, Therapeutic (prospective cohort study).

Keywords: biomechanics, gait studies, trauma, posterior malleolus, trimalleolar ankle fracture

Introduction

Posterior malleolar fractures are injuries to the posterior aspect of the tibial plafond commonly associated with trimalleolar rotational ankle fractures. These lesions occur in 7% to 44% of all ankle fractures and are distinguished from pilon fractures by the lack of supra-articular metaphyseal extension and articular impaction seen in those types of injuries involving more axial loading.[11] Significant debate continues to exist surrounding the contribution of the posterior malleolus to the stability of the ankle joint, and there is currently no consensus as to which posterior malleolar fractures require operative fixation. Earlier studies suggested that fractures involving >25% of the articular surface significantly reduced the tibiotalar contact area and proposed that this may lead to increased joint stress forces and rates of arthrosis.[9,13] More recent

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studies have demonstrated that patients sustaining unstable ankle fractures with an associated posterior malleolus fracture report worse outcomes 1 year after operative fixation, although this difference appears to even out by 2 years.[21] Medium and large posterior fragments (>5% of the articular surface) have demonstrated increased post-traumatic radiographic osteoarthritis than smaller (<5%) fragments,[3] and syndesmotic instability was shown to be reduced in trimalleolar ankle fractures when direct fixation of the posterior malleolus was first performed.[16]

However, other investigations have suggested that the posterior malleolar fragment is not as vital to patient outcomes as once believed. Studies have indicated that contact stress forces do not significantly increase, with simulated fractures involving up to 50% of the joint surface.[6] Research evaluating restraints to posterior instability of the tibiotalar joint demonstrated that the fibula and AITFL are the primary restraints to posterior translation rather than the posterior malleolus.[19] Furthermore, a recent systematic review of posterior malleolar fractures was unable to demonstrate that posterior fragment size was an indication for fixation; instead, step-off appears to be a more important indicator for the development of posttraumatic osteoarthritis and worse functional outcomes.[23] Therefore, whether fixation is necessary for these types of fractures remains a source of controversy.

However, most current research has focused on patient-reported outcome measures and cadaveric biomechanical analysis, with no significant literature investigating the impact of trimalleolar ankle fixation, and specifically posterior malleolar fixation, on gait. In the current study, patients with rotational trimalleolar ankle fractures who underwent operative treatment with stable syndesmotic examination after fixation were evaluated 6 months after surgery in a gait laboratory to evaluate for any clinically notable differences at short-term follow-up compared with younger healthy controls. In addition, subsets of patients with or without posterior malleolar fixation were further analyzed to determine its impact on gait within the same time period. Furthermore, these measures were then compared to historical values of populations of younger and elderly health adults found in the literature to determine the overall influence of operative fixation of these injuries on gait mechanics. We hypothesized that although patients sustaining trimalleolar ankle fractures would have worse gait parameters 6 months after operative treatment, patients whose posterior malleolus underwent operative fixation would not have significantly better gait than those who did not, as both cohorts were found to have a stable syndesmotic examination prior to leaving the operating room.

Materials and Methods

Patient Selection

The institutional review board (IRB) approved all portions of this study. Patients were prospectively identified who had undergone operative fixation of unstable closed trimalleolar ankle fractures (AO/OTA 44B3) between October 2014 and March 2017. Initial screening inclusion criteria required that patients be 18 years old or older at the time of their procedure and that they had undergone fixation of their trimalleolar ankle fracture by operative procedures coded with CPT code 27822 (fixation of the lateral and medial malleolus) or CPT code 27823 (fixation of the lateral, medial, and posterior malleolus). Posterior malleolar fixation was performed at the discretion of the operative surgeon at the time of the procedure based on his or her assessment of syndesmotic stability after evaluation and treatment of the medial and lateral malleoli. Exclusion criteria included patient younger than 18 years, pregnancy at the time of screening or testing, status as a prisoner at the time of screening or testing, additional injuries that in the opinion of the primary investigator might skew results of the gait analysis (ie, polytrauma patients), or those patients who were unable to provide study consent for themselves for any reason. All patients followed the same postoperative protocols with 6 weeks of non-weightbearing followed by progressive weightbearing and weaning of an ankle immobilization orthotic. Patients were approached at their routine 3-6-month postoperative follow-up appointments and asked to participate in a gait analysis 6 months after their index procedure. Patients were included in the analysis if they met all of the inclusion criteria, none of the exclusion criteria, and completed the gait analysis. Fifty-nine patients were identified who met the initial screening criteria. Of these, 31 patients were ruled ineligible to participate in the study according to the exclusion criteria before being approached. Twenty-eight patients were asked to participate in the study. Ten patients refused. Eighteen patients consented to the study, with 2 patients meeting the exclusion criteria during postconsent screening. Therefore, 16 patients were eligible to participate in the study, of which 10 followed through with gait analysis: 5 patients with posterior malleolar fixation and 5 patients without.

Healthy control subjects were chosen from a pool of healthy volunteers with the following exclusion criteria: younger than 18 years, pregnancy at the time of screening or testing, status as a prisoner at the time of screening or testing, medical history significant for gait abnormality, or those patients who were unable to provide study consent for themselves for any reason. Seventeen subjects were identified and were able to complete the gait analysis.

Fracture Characteristics

Lateral radiographs of the fractured ankle from the time of surgery were evaluated using the Sectra IDS7 imaging suite (version 21.2). The dimensions of the tibial plafond were calculated as previously described.[17] The length of the intact plafond (A) was measured from the most anterior aspect of the articular portion of the plafond to the intra-articular fracture line. The fracture fragment length (B) was measured from the most posterior aspect of the articular portion of the plafond to

Table 1. Patient Demographic Characteristics.[a]

Characteristic	Controls (n=17)	Ankle Fractures (n=10)	*P* Value	Unfixed Posterior Malleolus (n = 5)	Fixed Posterior Malleolus (n = 5)	*P* Value
Sex (male-female)	7:10	3:7	.56	1:4	2:3	.15
Age at surgery/analysis (controls), y	27 (21-41)	51 (18-75)	<.001**	48.8 (32-58)	53.2 (18-75)	.69
Height, m	1.72 (1.58-1.88)	1.70 (1.63-1.78)	.60	1.70 (1.68-1.73)	1.70 (1.63-1.78)	.99
Weight, kg	72.1 (53.1-99.2)	81.8 (63.5-113.4)	.11	84.4 (63.5-113.4)	79.3 (69.8-90.7)	.61
BMI	24.5 (18.9-36.4)	28.4 (22.1-39.2)	.07	29.2 (22.6-39.1)	27.62 (22.1-32.3)	.68
Time from surgery to gait analysis, mo	–	5.9 (5-7)	–	6 (5-7)	5.8 (5-7)	.69
Fracture characteristics						
Fracture fragment length, mm	–	9.6 (5.2-14.9)	–	8.0 (7.0-9.3)	10.8 (5.2-14.9)	.21
Intact plafond length, mm	–	29.7 (21.0-37.0)	–	31.8 (26.0-37.0)	28.1 (21.0-32.8)	.27
Percentage total length of fracture, %	–	24.3 (15.1-38.9)	–	20.2 (15.9-23.0)	27.6 (15.1-38.9)	.18

Abbreviation: BMI, body mass index.
$^*P < .05$, $^{**}P < .001$.
[a]Data are presented as mean (range).

the fracture line. The percentage total length of fracture was calculated using the following formula: $[B / (A+B)] \times 100$.

Biomechanical Testing

All gait studies were performed by a blinded investigator trained in motion testing 6 months after the index procedure. Seventeen healthy volunteers without any history of significant lower limb injury or pain comprised the control group with 10 in the experimental group. Three-dimensional kinematics were captured using an 8-camera Vicon Motion Analysis System (Oxford Metrics, UK) at a sampling rate of 100 Hz.[22] Fifteen reflective makers were placed on specific anatomic locations according to the Helen Hayes model which included the sacrum, bilateral anterior superior iliac spine, thigh, knee, shank, lateral malleolus, heel and second metatarsal.[12] Each participant was weighed and measured to obtain parameters for Vicon Nexus. Participants were asked to walk with their natural cadence down a 10-m walkway in barefoot conditions. The walking trials were completed once a minimum of 10 trials were captured. Six trials were used for analysis. All trials had at least 1 complete stride per side available for analysis. The analysis included spatiotemporal values including cadence, swing time, double leg support time, stance phase time, step length, stride length, stride time, and walking speed. Data were filtered using a General Cross Validation (GCV) Woltring filter.[8] The average values plus 1 standard deviation for each participant were then compiled in one database. These values were again averaged together among the participants to result in a final average plus 1 standard deviation.

Literature Search

A MEDLINE search for the term "normative spatiotemporal gait parameters" was used to identify references from which bibliography references were evaluated to mine for further citations. References were evaluated for inclusion of the tested spatiotemporal parameters and detailed demographic data to allow for determinations of age. Two were selected based on these criteria: Pietraszewski et al and Hollman et al.[10,18] When available, "preferred" walking speed was chosen for analysis, as this was comparable to the self-selected walking speed used in the gait analysis of the ankle fracture patient cohort.

Statistical Analysis

Statistical analysis was completed using Microsoft Excel (version 16.21). Categorical variables were analyzed using a χ^2 test, and continuous variables were evaluated with a 2-tailed, unpaired Student *t* test. A *P* value of less than .05 was considered to be statistically significant. Power analysis performed with G*Power (version 3.1) with a $(1 - \beta)$ value of 0.80 and an α value of 0.05 demonstrated that 9 patients per arm would be required to determine a difference in walking speed of 0.2 m/s.

Results

The spatiotemporal gait measurements of 17 health control patients were compared with those of 10 fracture patients available for analysis: 5 with posterior malleolar fixation and 5 without fixation. Although the control patients were demonstrated to be younger ($P < .001$) and trended toward a lower body mass index ($P < .07$), all other patient characteristics were otherwise similar between the 2 groups (Table 1). The demographics between fracture patients treated with operative and nonoperative management of the posterior malleolar fracture fragment were also compared and not found to be significantly different. Fracture characteristics were also compared between the 2 groups by calculating the percentage of the articular surface that the posterior malleolar fracture fragment represented; these too were not found to be significantly different.

Temporospatial parameters of gait, including cadence, swing time, double leg support time, stance phase time, step length, stride length, stride time, and walking speed, were

Table 2. Gait Cycle Spatiotemporal Measurements of Patients With Trimalleolar Ankle Fractures After Open Reduction and Internal Fixation Compared With Healthy Controls as Well as Young[18] and Elderly[10] Literature Controls.

Gait Metric	Ankle Fractures, Mean ± SEM	Controls, Mean ± SEM	*P* Value	Young controls (Pietraszewki), Mean ± SEM	*P* Value	Elderly Controls (Hollman), Mean ± SEM	*P* Value
Cadence, steps/min	101.84 ± 2.98	118.00 ± 1.94	<.001**	110.40 ± 2.04	.02*	102.00 ± 1.54	.96
Swing phase time, s	0.45 ± 0.01	0.40 ± 0.02	<.001**	0.37 ± 0.01	<.001**	0.43 ± 0.01	.08
Stance phase time, s	0.74 ± 0.03	0.61 ± 0.02	<.01*	0.72 ± 0.02	.36	0.75 ± 0.02	.78
Double leg support time, s	0.32 ± 0.02	0.21 ± 0.02	<.01*	0.18 ± 0.01	<.001**	0.31 ± 0.01	.55
Step length, m	0.56 ± 0.02	0.66 ± 0.01	<.01*	0.63 ± 0.01	<.01*	0.69 ± 0.02	<.001**
Stride length, m	1.10 ± 0.05	1.32 ± 0.03	<.01*	1.47 ± 0.03	<.001**	1.39 ± 0.03	<.001**
Stride time, s	1.19 ± 0.03	1.02 ± 0.02	<.001**	1.09 ± 0.02	.69	1.18 ± 0.02	.72
Walking speed, m/s	0.94 ± 0.06	1.30 ± 0.03	<.001**	1.36 ± 0.01	<.001**	1.17 ± 0.03	<.001**

Abbreviation: SEM, standard error of mean.
*$P < .05$, **$P < .001$.

Table 3. Comparison of Gait Cycle Spatiotemporal Measurements of Patients With Trimalleolar Ankle Fractures After Open Reduction and Internal Fixation Without ("Unfixed") and With ("Fixed") Posterior Malleolar Fixation.

Gait Metric	Unfixed Posterior Malleoli, Mean ± SEM	Fixed Posterior Malleoli, Mean ± SEM	*P* Value
Cadence, steps/min	105.52 ± 3.99	98.16 ± 4.17	.24
Swing phase time, s	0.45 ± 0.01	0.45 ± 0.01	.73
Stance phase time, s	0.70 ± 0.03	0.78 ± 0.05	.21
Double leg support time, s	0.29 ± 0.02	0.36 ± 0.04	.18
Step length, m	0.59 ± 0.03	0.53 ± 0.02	.21
Stride length, m	1.14 ± 0.06	1.06 ± 0.08	.42
Stride time, s	1.15 ± 0.04	1.24 ± 0.05	.22
Walking speed, m/s	1.01 ± 0.07	0.88 ± 0.09	.30

Abbreviation: SEM, standard error of mean.
*$P < .05$, **$P < .001$.

compared between the healthy controls and fracture patients (Table 2). All measurements were found to be significantly different between the 2 groups. However, when these measurements were compared between patients undergoing fixation or no fixation of the posterior malleolar fragment, none of these measurements were found to be significantly different ($P > .05$) (Table 3).

The overall effect of operative fixation of trimalleolar ankle fracture was then compared to historic values found in the literature of younger (age 22-24) and elderly (age 70-74) healthy controls (Table 3) by pooling together patients with and without posterior malleolar fixation. Cadence, swing time, double leg support time, step length, stride time, and walking speed were found to be significantly different between the trimalleolar ankle fracture patients and younger healthy controls whereas stance phase time and stride time were similar. In contrast, only step length, stride length, and walking speed were found to be significantly different between the ankle fracture patients and elderly controls.

Discussion

The operative indications for posterior malleolar fixation in the treatment of trimalleolar ankle fractures remain a topic of controversy. A recent survey of members of the Orthopaedic Trauma Association (OTA) and the American Orthopaedic Foot & Ankle Society (AOFAS) conducted by Gardner et al demonstrated significant variability in the treatment of these fractures even among fellowship-trained surgeons.[7] One of the most accepted indications for operative intervention has been fragment size, with fragments incorporating greater than 25% of the articular surface undergoing open reduction and internal fixation in order to decrease rates of posttraumatic arthrosis.[3] This value is based in part on work by McDaniel et al comparing open reduction and fixation with closed treatment of trimalleolar ankles fractures, with those patients undergoing closed treatment experiencing worse functional outcomes.[14] However, findings such as these do not accurately reflect the current treatment algorithms for this type of injury nor do they address the stability of the ankle joint. More recent studies suggest that fragment size may not be the most important factor in dictating functional outcomes. De Vries et al evaluated 45 patients with ankles fractures and a posterior malleolar fragment and found that although larger fragments were more likely to be fixated, there was no correlation between clinical outcome measures and fragment size at a mean follow-up of 13 years.[2] Instead, the quality of the reduction and the stability of the syndesmosis appear to be key.[15,20] Studies have shown that smaller posterior malleolar fragments do not affect ankle joint stability, and fragment size likely represents a confounding variable in patient outcomes.[5]

However, there are limited data of the effect of trimalleolar ankle fracture fixation and specifically fixation of the posterior malleolus on gait. Elbaz et al demonstrated that patients who had undergone operative treatment of ankle fractures had significant changes in their gait parameters compared with healthy controls but did not stratify patients by injury or method of fixation, whereas Wang et al found evidence of posttraumatic stiffness 1 year after treatment of operative ankle fractures but did not differentiate between fixation strategies.[4,24] These data indicate that the functional status is significantly affected not only by the injury itself but also by the manner in which operative stability is achieved.

The present study aimed to clarify how operative treatment of trimalleolar ankle fractures affects gait kinematics in the early postoperative period, as early signs of gait issues may be reflective of poorer outcomes long-term. Our data suggest that while patients with these fractures have significantly worse gait when compared to controls, the operative treatment of the posterior malleolar fragment does not appear to significantly alter most gait measurements after ankle fracture repair. A key factor in these findings is that the syndesmosis was tested after fixation and found to be stable with stress examination under fluoroscopy, suggesting that ankle joint stability is more critical to improved functional outcomes. Furthermore, the size of the articular fragment was found to be similar between the 2 groups supporting prior evidence suggesting that fragment size is likely not the most important variable leading to posttraumatic osteoarthrosis after these injuries.[23]

Additionally, patients undergoing operative treatment of trimalleolar ankle fractures with or without posterior malleolar fixation were compared to a healthy control population as well as literature values of 2 separate cohorts of healthy controls: younger (ages 22-24, Pietraszewski et al[18]) and elderly (ages 70-74, Hollman et al[10]). With the exceptions of stance phase time and stride time, all other record spatiotemporal gait parameters were significantly different between the ankle fracture cohort, the healthy controls, and the literature values for younger healthy patients. In contrast, the ankle fracture patients were found to have gait characteristics more similar to healthy elderly patients. This suggests that patients undergoing operative treatment of trimalleolar ankle fractures do not achieve restoration of normal physiologic gait in the short-term, instead demonstrating a slower, shorter gait more similar to healthy older individuals.

The impact of these findings is restricted by several limitations. The most significant of these is the small sample size. Only 10 patients who met the inclusion criteria were able to complete the gait analysis, leaving the study open to type II error. However, a priori power analysis indicated that the study was adequately powered to identify a 0.2-m/s difference in walking speed, representing the minimal clinically important difference.[1] Patient enrollment was limited by several factors. More than 50% of patients who met the initial inclusion criteria were removed during the screening process, primarily because of concomitant injuries that may have affected the gait analysis. One-third of those patients approached refused to participate, and of those who consented to the study, only 55% completed the gait analysis. Of the initial patients screened, only 17% were available to be analyzed. It appears that patient interest in the study was limited, causing the study to be susceptible to selection bias. In addition, the exclusion of patients with concomitant injuries at the surgeons' discretion is another important source of possible bias.

The small sample size may have an effect on the differences in the fracture characteristics seen between those patients who underwent fixation vs those who did not. The percentage total length of the fracture fragment in those patients that were fixed demonstrated a higher mean value (27.6% vs 20.2%) than those that were not fixed. Although this was not found to be statistically significant, this may suggest that because of the fact that worse fractures are receiving fixation, their gait mechanics are equivalent to less severe fractures that do not receive fixation, whereas if these fractures were not fixed a more notable difference may have been seen.

Patients and fixation were not prospectively randomized—patients were identified and recruited postoperatively with the fixation technique left to the preference of 1 of 3 fellowship-trained attending orthopedic traumatologists, each with their own potential biases regarding operative fixation. Moreover, specific methods of posterior malleolar fixation (plate vs screw fixation) were not stratified although reports indicate that fixation strength may not significantly differ between the 2 modalities.[25] Finally, all patients were tested at 6 months postoperatively, which may be too early to accurately characterize any differences; conversely, the earlier time point may instead accentuate differences between healthy controls and the trimalleolar fracture cohort.

There were weaknesses in the control groups as well. Ideally, an age-matched control group would have been incorporated into the study, as the current healthy control population was significantly younger and trended toward a lower body mass index than the fracture patients. This may explain the differences noted in the gait analysis and may not be attributable to the ankle injury and/or fixation. However, literature values of gait of both younger and older healthy controls also demonstrate differences in walking speed, step length, and stride length, suggesting that although age may explain some of the results, it does not offer a complete description of the data. Additionally, although "normal walking speed" was chosen when available from the literature, these values were found to be faster when compared to the ankle fracture group, which may affect the comparisons between the other gait parameters evaluated. Comparison to literature values is suspect to other biases. Although the gait measurements of specific limited age ranges can be readily identified, the ankle fracture cohort represents a wide range of ages. In addition, both sexes were included in the ankle fracture cohort whereas only males were reported for the literature values. Differences in measurement standards and equipment as well as unreported characteristics such as the ethnicity of the literature values may also contribute as confounders.

In conclusion, these findings suggest that fixation of trimalleolar ankle fractures leads to a gait more similar to older rather than younger healthy adults at 6 months after surgery. The gait of patients undergoing operative treatment of trimalleolar ankle fractures appears to be slower with shorter steps but represents a gait similar to that of functional older adults. However, inclusion of the posterior malleolus within the fixation construct does not appear to significantly impact gait during this time. Therefore, operative technique should focus on achieving a stable ankle syndesmosis. Furthermore, the results of this study focus only on the short-term outcomes after surgery; further research is needed to determine long-term differences in gait.

Ethical Approval

Ethical approval for this study was obtained from University of Pennsylvania Institutional Review Board IRB PROTOCOL#: 821263.

Declaration of Conflicting Interests

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