# Improved Function and Joint Kinematics After Correction of Tibial Malalignment

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## **Abstract**

Malunion after tibia fracture can have a negative effect on a patient's gait, joint kinematics, and functional outcome.

We conducted a study to determine whether surgical correction of malunited tibias improves gait, joint kinematics, and patients' perception of their health and overall well-being.

Eleven patients with tibial malunions were treated with osteotomy, deformity correction, and open reduction and internal fixation (ORIF). Minimum follow-up was 7 months (mean, 11 months; range, 7-17 months).

In all cases, the osteotomy eventually healed. Two patients needed revision surgery: One had late collapse of the regenerate bone and underwent revision ORIF away from the site of deformity correction; the other required exchange intramedullary nailing. Surgical correction of malunited tibia fractures resulted in significant improvement toward the normative in lower extremity joint kinematic values and patients' perceptions of their health and overall well-being. Surprisingly, there was little effect on gait.

Symptomatic malunited tibia fractures should undergo surgical correction, as it is likely to improve overall lower extremity function and patient satisfaction.

The tibia is the most commonly fractured long bone in adults, and tibial malunions occur in up to 60% of these patients.1,2 Persistent tibial malalignment, particularly varus alignment, negatively alters gait and joint kinematics, leading to altered weight-bearing forces across the knee and ankle joints. These altered forces may lead to osteoarthritis.<sup>3-8</sup>

Several studies have identified a relationship between extent of tibial malalignment and changes in joint reaction forces. $3,5-7,9-13$  Puno and colleagues<sup>14</sup> developed a mathematical model to better define the changes in neighboring joints relative to the pattern of the tibia malalignment. Not surprisingly, their work showed that, with distal tibial malunions, altered stress concentrations were realized at the ankle joint,

and more proximal tibial deformities led to larger alterations in the joint stresses at the knee. More recently, van der Schoot and colleagues<sup>8</sup> found a high prevalence of ipsilateral ankle osteoarthritis with tibial malalignment of 5° or more, and Greenwood and colleagues<sup>15</sup> showed a higher incidence of knee pain, lower limb osteoarthritis, and disability in patients with previous tibia fractures. Given these findings, it would seem that correction of tibial malalignment would lead to normative lower extremity joint kinematic values, joint reaction forces, and overall quality of life (QOL).

The ability to ambulate has been recognized as an important milestone in functional recovery after lower extremity injury.2,16,17 Gait analysis, assessment of joint kinematics, and QOL and health status questionnaires can provide information to evaluate rehabilitation protocols, treatment algorithms, and surgical outcomes. Recently, these measures have been used to assess patients recovering from acetabular fractures, femoral shaft fractures, and calcaneal fractures.<sup>4,11,17-24</sup> However, no study has used these measures to assess the benefits of surgical correction of malaligned tibias.

We conducted a study to determine improvement in gait, joint kinematics, and patients' perceptions of overall wellbeing after surgical correction of tibial malunions. The null hypothesis was that correction of tibial malunion would have no effect on gait, joint kinematics, or patients' perceptions of function and QOL.

# **Materials and Methods**

This prospective double-time-point study, which was approved by the Institutional Review Board of Washington University/ Barnes-Jewish Hospital, evaluated 11 consecutive patients with a varus tibial malunion treated by a single surgeon between September 2003 and January 2006. All patients were treated using a technique that included oblique osteotomy and open reduction and internal fixation (ORIF) or osteotomy and intramedullary nailing. Study inclusion criteria were age 18 years or older; symptomatic varus malunion of the tibia of 10º or more; absence of a developmental or pathologic process leading to the fracture and subsequent deformity; no neurologic deficit of either lower extremity or contralateral lower extremity deformity; and ability to ambulate 9 meters with or without use of an assistive device.

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## Table 1. **Patient Characteristics**



<sup>a</sup>Complications occurred in patients 4 (collapse of regenerate) and 5 (nonunion).

The 11 patients (6 men, 5 women) who met these criteria enrolled in the study. Mean age was 53 years (range, 43-68 years). Eight malunions involved the left tibia. The mechanisms of injury were motor vehicle crash (6 patients), fall from a great height (3), being struck by a motor vehicle (1), and gunshot (1). Mean time from injury to corrective surgery was 16.9 years (range, 1-34 years). Before surgery, each patient had a thorough physical examination, with plain radiographs, including anteroposterior (AP), lateral, and oblique views, obtained to assess degree of limb malalignment. Patients completed the Short Form-36 (SF-36) and the Musculoskeletal Function Assessment (MFA) and underwent joint kinematics and gait analysis. Five malunions were located in the mid-diaphysis of the tibia, 3 in the proximal third, and 2 in the distal third of the tibial shaft. One patient had posttraumatic deformity involving the proximal and the mid-diaphysis (**Table 1**). After surgery, each patient was followed at regular intervals in the surgeon's private office. Minimum follow-up was 7 months (mean, 11 months; range 7-17 months). At follow-up, radiographs were obtained, and each patient completed the SF-36 and the MFA and underwent joint kinematics and gait analysis.

We obtained preoperative AP and lateral radiographs of the

# Table 2. **Radiographic Measurements of Deformity**



a Significantly different from preoperative (*P* < .05).

malaligned and contralateral normal tibias for each patient. Angular deformity was determined in the sagittal and coronal planes to determine location and magnitude of the deformity. Specifically, on each AP and lateral radiograph, a line was drawn the length of the tibia proximal and distal to the area of the deformity. The angle generated by the intersection of these lines on the AP and lateral radiographs was then plotted on a grid to determine the precise plane and magnitude of the deformity (Table 2).<sup>1,12</sup> Clinically, relevant rotational deformity of the involved limb was assessed by physical examination, and the results were compared with those of the contralateral limb. Owing to the lack of considerable rotational deformity in any of these 11 patients, we did not obtain computed tomography scans for further assessment of rotation.

Perioperative intravenous antibiotics were administered: 2 g cefazolin 30 minutes before incision and 1 g every 8 hours for 24 hours after surgery. A pneumatic tourniquet was placed on the proximal thigh, and the entire leg was prepared and draped in a sterile fashion. The limb was elevated and exsanguinated with an Esmark bandage and the tourniquet raised to 250 mm Hg. With fluoroscopy, the site of the tibial deformity was identified. Generally, an incision was made centered over the apex of the deformity and one fingerbreadth lateral to the palpable tibial crest. In most cases, the anterolateral aspect of the tibia was exposed while minimizing soft-tissue and periosteal stripping. The plane of the maximum deformity was identified with both direct visualization and fluoroscopy. The osteotomy was performed with an oscillating saw, and in each case a fibular osteotomy was also performed. Malalignment was corrected using a combination of manual manipulation and femoral distractor.25,26 Intraoperative biplanar radiographs were compared with our preoperative plan and with reversed images of the contralateral tibia to assess correction of the deformity. If lengthening was required, in addition to the tibial osteotomy, a corticotomy was created, and a circular external fixator applied and distraction osteogenesis performed.

We maintained the limbs in a short-leg splint for about 10 days after surgery and then initiated active-assisted range of motion of neighboring joints. Patients were maintained on toe-touch weight-bearing for the initial 6 weeks and were then advanced to partial weight-bearing (23 kg). Physical therapy for lower extremity strengthening and gait training was started 6 weeks after surgery. Three months after surgery, patients were advanced to weight-bearing as tolerated and were allowed to return to their activities of daily living without restrictions if radiographs and clinical examination were consistent with healing of the osteotomy.

Each patient was examined and radiographs obtained at regular intervals (2, 6, and 12 weeks and then about every 3 months) after surgery until healing. Bone union was determined by history and physical examination with pain-free weightbearing without use of assistive devices and by return of functional use of the extremity. Radiographic union was considered to have occurred when bridging trabeculae were present across the osteotomy and there was no loosening or failure of the implants. Occasionally, if there were questions regarding healing, a musculoskeletal radiologist was consulted. Acceptable tibia alignment was defined as alignment of less than 5° varus or less than 10° valgus in the coronal plane and less than 15° procurvatum or recurvatum in the sagittal plane. Immediate postoperative radiographs and most recent radiographs were used to determine the final amount of angular correction.<sup>27</sup>

Two patients subsequently required secondary operative procedures. One had varus collapse through the regenerate, and the other developed a nonunion of the osteotomy site and required exchange intramedullary nailing. In each case, the final assessment was done after the patient had healed after the second surgery and had fully recovered.

#### Perceived Functional Assessment

The MFA is a 100-item self-administered QOL questionnaire designed to assess self-perception of physical, psychological, and social well-being in patients with a musculoskeletal injury or condition. The MFA provides a summary score and separate score for each of 10 functional domains. The lower the score, the better the patient's perception of function. Validated and published norms are available.<sup>20,28-30</sup>

#### Perceived Health Status

The Short Form-36 is a 36-item multipurpose self-administered health survey questionnaire. The SF-36, which assesses overall health status, provides a Physical Component Score (PCS) and a Mental Component Score (MCS). The higher the score, the better the patient's perception of function. Validated and published norms are available.<sup>31</sup>

#### Gait Analysis

Video data from a 6-camera high-resolution system (Motion Analysis, Santa Rosa, California) were used to assess gait. A set of 3 reflective surface markers was placed on each of 4 areas: trunk, thighs, legs, and feet.<sup>18,19</sup> The patient walked barefoot along a 9-meter walkway, and video data were collected during the middle 2 meters. For each patient, data from 4 to 7 trials were collected. Computerized software produced data describing the averaged joint angle as a function of the gait cycle for each of the 3 principal planes of the body. Specific points in the gait cycle were analyzed. Variables included maximum knee varus in stance phase; maximum knee valgus in swing; maximum knee flexion in stance and swing; minimum knee flexion in stance; maximum ankle inversion in terminal stance; maximum ankle eversion in stance; maximum ankle dorsiflexion in stance and swing; and maximum ankle plantarflexion at takeoff. In addition to the lower extremity joint kinematics, angular measurements, basic gait measurements of step length, stride length, cadence, and speed were also recorded.

## Statistical Analysis

Paired *t* tests were used to determine if significant changes occurred as a consequence of the surgery for the outcome variables (*P* < .05). Normative gait data were used to assess the quality of any changes that occurred in the variables, but no statistical analysis was performed to determine significant differences.<sup>18</sup>

#### **Results**

All 11 patients had clinical and radiographic evidence of healing and deformity correction at most recent follow-up. Nine patients (82%) healed after the index procedure. Mean total angular correction in the coronal plane was 21° (range, 14° varus to 7° valgus), and mean total angular correction in the sagittal plane was 9° (range, 21° recurvatum to 15° procurvatum) (**Table 2**).

For the group, mean preoperative MFA score was 39 (SD, 18; range, 10-69), and mean postoperative MFA score was 28 (SD, 14; range, 8-53). Patients reported the most improvement in 2 domains: In Leisure, mean (SD) preoperative score was 8 (2), and mean postoperative score was 5 (2); in Emotional, mean preoperative score was 5 (2), and mean postoperative score was 4 (1). The other domains were not significantly different between the 2 assessments.

 On the SF-36, mean (SD) PCS significantly (*P* < .05) improved from 32 (8) to 43 (9). Mean (SD) MCS showed little change: preoperative, 46 (16); postoperative, 48 (13). The PCS subcategories that showed the most improvement were Physical Function, mean (SD) preoperative, 26 (20), to postoperative, 52 (26); Role of Physical Health, preoperative, 18 (24), to postoperative, 60 (41); and Bodily Pain, preoperative, 39 (27), to 58 (18).

The results from the preoperative and postoperative gait analysis showed no significant differences for the ankle, knee, and hip variables during swing phase (**Table 3**). In an analysis of the changes in joint kinematics during stance, maximum hip adduction (increased) and maximum knee varus (decreased) on the operative side were significantly improved toward normative values as a consequence of the surgery (**Table 3**). The

## Table 3. **Preoperative and Postoperative Values for Joint Gait Kinematics, With Values for Persons Without Disability Presented for Comparison**



a Standard deviations were not supplied to prevent too great a comparison between the treatment group and the group without disability. The purpose of the paper was to compare the changes within the operative group. bSignificantly different from preoperative (*P* < .05).

other kinematic stance variables were not significantly different. No significant changes were observed in stance time, step length, stride length, cadence, or speed as a consequence of the surgery (**Table 4**).

## **Discussion**

Correction of malaligned tibias leads to improved limb alignment and patients' perceptions of functional abilities and health but had a limited effect on joint kinematics and gait. In a group of like patients, we used common techniques to realign malunited tibias and validated instruments to measure functional outcome, health status, joint kinematics, and gait. The goals of this study were to evaluate changes in perceived function and health status and changes in joint kinematics and gait as a result of correction of a posttraumatic limb deformity.

Other investigators have reported outcomes of treating symptomatic malunions,<sup>32</sup> nonunions,<sup>24</sup> and leg-length discrepancies.<sup>33</sup> In these reports, correction of deformity improved patient satisfaction and function, though objective means of assessment were infrequently used. Good results were reported with use of a dome-shaped supramalleolar osteotomy for the correction of tibial malunion.32 In this study, supramalleolar osteotomy was performed on 8 patients for correction of a malunited tibia. Postoperative assessment included subjective assessment of pain, limp, appearance, instability, and activity. Of these 8 patients, 7 reported overall symptomatic improvement after healing, and the 1 who lost the deformity correction remained symptomatic. Significant improvement in overall health has been reported after successful treatment of tibia nonunions.<sup>24</sup> The investigators used the SF-36 to assess patients who underwent treatment for a tibial nonunion. Analysis of these patients' results showed a significant improvement in physical and mental functioning after healing. In addition, improved gait symmetry was reported in patients successfully treated for leg-length discrepancies.<sup>33</sup> Unfortunately, how improvement in gait related to overall patient function was not assessed. In the present study, we used stringent objective and subjective validated instruments to assess changes in joint gait kinematics and functional outcome before and after treatment of a tibial malunion. In general, our results are consistent with published results and indicate that realignment of tibial malunions improves patients' perceptions of function. Our results also indicate improvements toward normative values in maximal hip adduction and knee varus, thus confirming the efficacy of the surgery from a functional perspective. Unfortunately, we did not show significant improvements in the remaining joint kinematics measurements or temporal gait parameters.

It is not entirely clear whether tibial malalignment leads to degenerative changes of the ipsilateral knee and/or ankle and what role this might play in functioning. In a retrospective analysis of 92 patients, angular deformity within 15° of normal alignment did not lead to ankle arthrosis.<sup>9</sup> Milner and colleagues<sup>4</sup> found that, though varus malunion of the tibia may lead to arthrosis of the medial compartment of the knee, other factors were more important in causing arthrosis of the ankle.

Wu and colleagues<sup>34</sup> used tibial osteotomies in New Zealand white rabbits to inves-

tigate cartilage and bone changes of the knee after creation of varus or valgus tibial deformities. Thirty-four weeks after osteotomy, rabbits with up to 30° of deformity had severe cartilage changes with osteophytes, fibrillation, derangement of cell columns, and associated increased subchondral bone density of the knees. Cadaveric studies have also shown increased contact pressures within the knees and ankles with ever increasing amounts of tibial deformity.<sup>6,10</sup> In each cadaveric study, malalignment in the distal third of the tibia caused the largest changes in the ankle, and changes in the alignment in the proximal third caused the largest changes in the knee.

Consistent with these animal and cadaveric studies are several retrospective clinical studies that have correlated tibial malalignment (particularly varus) with development of knee and ankle arthrosis.<sup>3,5,8</sup> Kettelkamp and colleagues<sup>3</sup> found a direct correlation between magnitude of deformity and length of time with development of knee arthrosis. These findings have led many to recommend that surgeons try to restore tibial alignment to as near normal as possible to reduce the likelihood of arthrosis after tibia fracture. We found significant improvement toward normative values for maximum hip adduction (increased) and tibial varus (decreased) after surgery. These improvements would shift the weight-bearing forces back to the central part of the knee and therefore more uniformly distribute weight-bearing forces.

Posttraumatic arthrosis that develops after fracture is thought to result from increased joint pressures and possibly factors related to the injury. Although surgical correction of tibial alignment is unlikely to reverse these cartilage changes, it may restore joint pressure symmetry and "offload" compromised compartments. Offloading of already degenerative compartments may explain our patients' improved perceptions of function and overall health status.

There were several limitations to our study. First, plain

# Table 4. **Preoperative and Postoperative Temporal Variables for Gait, With Values for Persons Without Disability Presented for Comparison**



a Standard deviations were not supplied to prevent too great a comparison between the treatment group and the group without disability. The purpose of the paper was to compare the changes within the operative group.

radiographs of malaligned and uninjured tibia and fibula were used, and these do not allow complete assessment of the weight-bearing access of the limb. Our patients, however, had isolated tibia fractures, which involved a normal limb before injury, so any alterations in joint kinematics, gait, or function would likely be the result of the fracture. Another limitation of our study is its nonrandomized design. However, the patients reflect the typical heterogeneous trauma patient population, who typically develop tibial malunions and seek correction. Another limitation was the lack of a treatment protocol regarding exact surgical technique and implants used to stabilize the osteotomies. In general, the patients were treated similarly, and their preoperative and postoperative assessments were exactly the same, as was their state-of-the-art joint kinematics and gait analysis, combined with the use of previously validated outcome measures. In addition, the lack of improvement in gait could have resulted from postoperative physical therapy that focused on joint mobilization and muscle strengthening and not on correction of abnormal gait parameters noted on preoperative gait analysis. Despite the potential limitations of the study, surgical correction of these symptomatic tibial malunions resulted in significant improvement in functional outcome and improved joint kinematics on the operative side.

# **Conclusion**

Significant effort should be made to restore and maintain nearanatomical tibial alignment until a tibia fracture is healed. In patients who develop a symptomatic tibial malunion, surgical correction should be undertaken with the intent to restore normal limb alignment and improve joint kinematics, function, and overall health status.

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