The relationship between gait and functional outcomes in patients treated with circular external fixation for malunited tibial fractures

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Highlights

- Correction of malunited tibial fractures associated with better improved outcomes.
- Positive relationship between gait and patient reported functional outcomes.
- Patient quality of life associated with patient perceived functional outcomes.
- VGA is good tool for monitoring progress and outcome in orthopaedic trauma.

Abstract

Background: Lower extremity fractures have a profound negative effect on a patient's gait and outcomes. Correction of deformity, and with it normalization of objective gait parameters, may result in better subjective and objective functional outcomes in patients treated with circular external fixation for malunited tibial fractures.

Aim: The purpose of this study was to investigate the relationships between gait parameters, patient reported outcome measures (PROMs), and health related quality of life measures in patients treated with circular external fixation for the correction of deformity related to tibial malunions.

Methods: This retrospective study included patients with posttraumatic tibial deformities, aged 14 to 65, with a minimum follow-up of 24 months following deformity correction. Patients with congenital deformities, head injuries, spinal cord injury, neurological disorders, or contralateral lower limb amputation were excluded. Functional outcomes were assessed by the Foot Function Index (FFI); Short Form 12 (SF-12); the EQ 5D; and the ASAMI score. Gait analysis was performed using Dartfish® and the Edinburgh Visual Gait Score (EVGS). The relationships between the EVGS and functional outcome scores were analyzed using Pearsons' moment correlations with Bonferroni corrections.

Results: Eleven patients with a mean age of 42 (range 23-57) were analyzed. The mean EVGS was 2.6±2.1, the mean FFI 29.6±33.4, the mean EQ5 Index Value 0.7±0.2, the mean EQ5 VAS 85.4±19.5, the SF12 mean Physical Component Score (PCS) 46.7±11.1, and the mean Mental Component Score (MCS) 55.2±7.5. The following relationships were strong and significant: EVGS and FFI (r=0.7; P=0.02), EVGS and PCS (r=-0.82; P=0.02), and FFI and EQ5 (r=-0.79, P=0.05).

Significance: The results of this study suggest that correction of deformity with realignment and restoration of normal anatomy was associated with improved functional outcomes and physical well-being. Patient reported quality of life is strongly associated with patient perceived functional outcome, but not with objective gait parameters.

Keywords:

Tibial malunion; complex trauma; gait analysis; patient reported outcome measures (PROMs); circular external fixation

Level of evidence

Level IV; case series

1. Introduction

Malunion following lower extremity trauma is common, with deformity related to alterations of alignment, length, or rotation, in isolation or in combination. Gait analysis provides an objective assessment of functional outcome in patients after lower limb trauma, and can assist in developing individual patient-adapted aftercare and rehabilitation protocols based on feedback from gait measurements (1, 2). Recent studies demonstrated significant alterations in gait patterns related to post-traumatic deformity, both during early rehabilitation and during long-term follow-up (1-11). Gait disturbances following lower extremity trauma may also be directly correlated with patient reported outcome measures (PROMs) and health related quality of care (1-3, 5, 9, 10, 12-14)

Warschawski et al. demonstrated a significant correlation between the Short Form SF-12 and abnormal gait patterns (2). Poor gait patterns were directly related to poorer Short Form-12 (SF12) scores (2). In patients with high energy tibial plateau fractures who were treated with circular external fixation had a significantly lower quality of life if gait abnormalities persisted, and in patients with high-energy tibial plafond fractures abnormal gait was directly related to fracture severity (9, 10). Van Hoeve et al. used gait analysis to investigate changes during push off and demonstrated a significant positive correlation between hindfoot range of motion, the Foot and Ankle Disability Index (FADI), the Short Form SF-36 physical component score, and range of motion between the hindfoot and tibia in the push-off phase calculated on gait analysis (4). The same research group identified similar relationships with respect to midfoot motion (5). In a group of 106 patients treated surgically with anterior cruciate ligament reconstruction, the GAITRite temporal and spatial gait-analysis system (measuring walking speed, cadence, and stride length, and relating this to Patient Reported Outcomes), revealed a strong correlation between gait and patient reported outcome measures (PROMS) (12, 13). Similarly significant correlations have also been observed in patients following total knee arthroplasty (15).

Functional outcomes following the management of tibial shaft fractures so far have focused on rates of fracture union, knee pain, joint stiffness, degenerative joint disease, rotational malalignment, and limitations in the activities of daily living and health-related quality of life (6). But there are currently few studies describing changes in gait patterns following tibial trauma (6, 14). The LEAP (Lower Extremity Assessment Project) study reported significant gait abnormalities following severe lower limb trauma, and correlated the decline in physical function with poor patient satisfaction (6, 14).

Gait analysis requires specialized equipment and is not commonly available, inhibiting its use in daily practice (16). However, simple video recording may have the potential to bridge this gap and assist in evaluating functional outcomes following lower extremity trauma (17). Dartfish® is a video analysis software package that enables the use of slow motion and image pauses to facilitate direct objective measurement of angles, distances, and timing on digital video recordings (18). The Edinburgh Visual Gait Score (EVGS) is a scoring system used to quantify gait quality, and consists of seventeen items based on the visual observation of gait in the sagittal and coronal planes (16, 17).

The purpose of this study was to, therefore, investigate the relationships between gait parameters, patient reported outcome measures (PROMs), and health related quality of life measures in patients treated with circular external fixation for the correction of deformity related to tibial malunions. We hypothesized that gait abnormalities and diminished performance related to tibial malunions, as measured by the EVGS and Dartfish® objective parameters, would positively correlate with inferior PROMs.

2. Methods

2.1. Study design

This retrospective cross-sectional study including all patients treated in circular external fixation for deformity correction of tibial malunions. The database of a specialized limb reconstruction centre was searched and all patients who were treated between January 2010 and December 2016 were enrolled if they met the following inclusion criteria: aged 14-65 years, treatment with a circular external fixator, removal of the fixator at least 24 months prior to study evaluation. Patients with congenital deformities, head injuries, spinal cord injury, neurological disorders, contralateral lower limb trauma or amputation, and patients who were unable or not willing to participate in the study were excluded. The institutional human research ethics committee approved the study, which was performed according to the principles of the Helsinki declaration; all patients gave written informed consent prior to enrollment. Basic demographic characteristics including age, gender, body mass index (BMI), trauma mechanism, duration of treatment, and complications were recorded. The primary outcome measures was the Foot Function Index (FFI); secondary outcome measures included the Short Form 12 version 2 (SF-12v2), and gait analysis using the Edinburgh Visual Gait Score (EVGS).

2.1.1. Surgical Technique

The magnitude of the tibial deformity was assessed as described by Paley and Tetsworth, as a uniapical deformity (19). When the femur is normal, a line drawn from the center of the femoral head through the center of the tibial plateau and extended distally defines the mechanical axis of the proximal tibia. When the ankle and distal tibia are normal, a line drawn from the center of the tibial plafond extending proximally perpendicular to the ankle joint orientation line defines the mechanical axis of the distal tibia. The center of rotation of angulation (CORA) is described by the intersection of these two mechanical axis lines, and defines the location and magnitude of the angular deformity (figure 1A). Hexapod circular external fixators were then applied as previously described (20), and a percutaneous osteotomy was performed as described by Tetsworth and Paley (21) (figure 1B). During gradual deformity correction the goals were to restore both the mechanical axis and all joint orientation lines to normal (19).

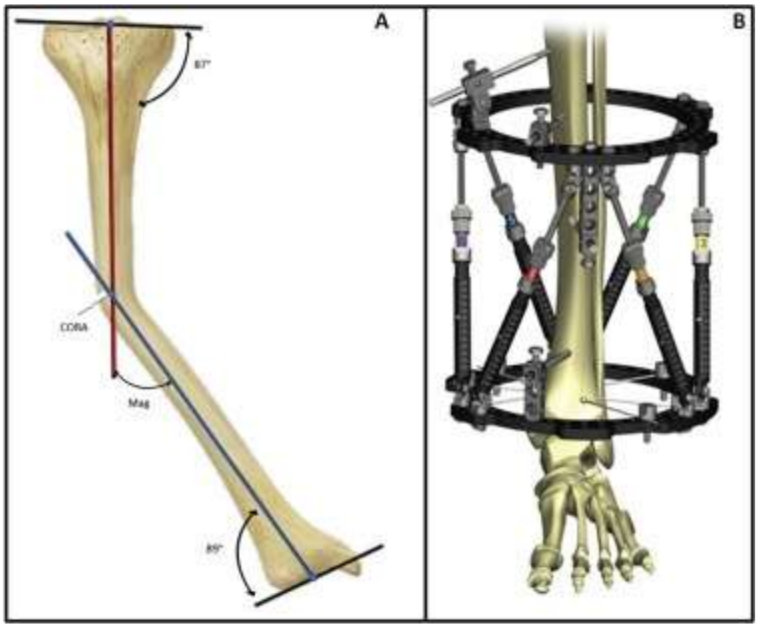

Fig. 1. (a) The amount of deformity is established by drawing a line from the center of the plafond extending proximally and from the center of the tibial plateau of the knee and extended distally. The center of rotation of angulation (CORA) is at the intersection of the two mechanical axis lines and is defines the angular deformity. (b) The principle of hexapod external fixation. Circular rings proximal and distal to the fracture are connect with 6 struts and fixed to the bone by wires or halfpins.

2.2.Gait assessment

Gait analysis was performed using video observed gait analysis (VGA). Video footage was obtained both in the sagittal and coronal planes while the patient was walking down a predetermined walkway (3.5m), returning to the starting point (7m). Patients walked barefoot at a self selected speed with the lower limbs exposed, starting 2 meters outside the cameras recording area. Video images were captured using an iPhone 7 Plus mounted on a tripod from the same positon for each patient (figure 2).

Fig. 2. Sagittal screenshot from the Dartfish® app using freeze-frame to demonstrate initial foot contact and measure ankle dorsiflexion at heel strike.

The Edinburgh Visual Gait Score (EVGS) was used to score gait. The EVGS provides a numerical score for each of 17 gait parameters for the foot, knee, pelvis, and trunk in both the stance and swing phase (22,23). In the development of the scoring system, the joint angle ranges were compared to standard references and divided into three degrees of severity: normal gait (score 0), moderate gait abnormality (score 1), or marked abnormality (score 2).

The scores of all 17 gait parameters were summed up. A total score of 0 signifies normal gait and any score >0 to a maximum score of 34 denotes abnormal gait (22,23). To increase reliability and accuracy for these gait parameters, Dartfish® application for iPhone was used (figures 4 and 5). The joint angles during the gait cycle were measured utilizing the tools from the Dartfish® application. Dartfish® is a video analysis software that allows objective measurement of joint angles and has been validated as a method to improve the reliability of observational gait parameters directly from digital video recordings, most importantly joint angles (18).

2.2.1. Outcome measures

Each patient completed the Foot Function Index (FFI), and the Short Form 12 Version 2 (SF-12v2). Patients independently completed these questionnaires on paper, and the research assistant was available to respond to requests for clarification in an effort to reduce reporting bias. The FFI is a clinical index, which provides a practical method for measuring foot function in an outpatient setting (24). The FFI consists of three sub-scales, the first measuring foot pain during various activities and the latter two measuring disability. It has been validated and provides meaningful data, especially in conjunction with other objective measures of patient outcome (25). Patients rate their foot pain from 1-10 at various times of day and during activities of varying intensity through seventeen questions. The FFI score is then calculated as a percentage, a low score indicating no foot pain and higher scores indicating pain at varying times and intensity. The SF-12 is a validated generic health related quality of life instrument that allows for measurement of physical and mental health component summaries. SF-12 is normalized for the physical and mental component scales to have a mean of 50 and a standard deviation of 10, with high scores representing better function and lower scores indicative of diminished function. Scores ≥50 represent no disability; 40–49, mild disability; 30–39, moderate disability; and below 30, severe disability.

2.3. Statistical Analysis

Raw data for the SF-12v2 and FFI were recorded using Microsoft Excel 2011, (Microsoft, Redmond, WA, 2011). The SF-12 data were scored using the SF-12v2 Health Outcomes Scoring Software Version 2.0 (QualityMetric Incorporated, Lincoln, RI, 2003). This software package generates output for all eight subscales of the SF-36, as well as for the Physical (PCS) and Mental Component Summary scales (MCS). Descriptive statistics were used to describe demographic variables, FFI, and SF-12. Categorical data was expressed as frequencies (ASAMI score). The relationships between the EVGS and functional outcome scores were analyzed using Pearson's moment correlations with Bonferroni corrections. A P-value of <0.05 was considered significant. All analyses were conducted using STATA SE (Version 12.0; StataCorp, College Station, Texas, USA) for Windows.

3. Results

Fifteen patients were identified and fulfilled the inclusion criteria for the study. One patient declined participation in the study, while three were unable to participate as they resided in regional areas, and were unable to return for further follow-ups. Eleven patients, eight males and three females with a mean age of 42 +/-17.4 (range 23-57) were included in the study. The baseline characteristics are presented in Table 1. Table 2 demonstrates the mean pre- and post-operative deformity angles. The coronal plane was corrected by a mean of 9.5 degrees and the sagittal plane deformity was corrected by a mean of 8.3 degrees.

Table 1: Baseline and demographic characteristics of study group

Age	42 (±17.4)
Gender, male/female	8/3
Smoker, yes/no	2/9
High/low energy trauma	7/4
Open/closed fracture	5/6

Table 2: Pre- and post-operative alignment angles (in degrees)

	Mean	**SD**	**Minimum**	**Maximum**
Coronal				
Pre-OP	13.6	8.1	3	29
Post - OP	4.1	3.3	0	9
Sagittal				
Pre-OP	13.4	11.2	0	34
Post - OP	5.1	6.6	0	18

3.1.Gait analysis

The mean EVGS score was 2.6 (±2.1) (Table 3). Of the observed abnormal parameters 90% (26 of 29) were noted in the foot. Seven patients demonstrated moderately reduced foot dorsiflexion in stance (10° plantarflexion - 4° dorsiflexion). In addition, six of these patients demonstrated moderately reduced foot dorsiflexion during the swing phase (6°- 20° plantar-flexion), and three patients demonstrated delayed heel rise (when heel lift occurs with or after opposite foot contact). One patient demonstrated moderately reduced dorsiflexion during the swing phase only. One patient demonstrated severe hindfoot varus during stance (more than 10° varus) in addition to reduced dorsiflexion in stance and swing, while four patients demonstrated moderate varus in stance (1° to 10° varus), in addition to moderately reduced ankle dorsiflexion in stance and swing. One patient demonstrated moderate dorsiflexion in stance with normal ankle dorsiflexion. Three patients were noted to have a decreased foot progression angle during stance (1°- 25° of internal rotation compared to the knee progression angle) in addition to reduced ankle dorsiflexion.

Table 3: Results of scoring systems

	Observations	Mean	Std Dev	Min	Max
EVGS	11	2.6	±2.1	0	6
FFI	11	29.6	±33.9	0	79.4
SF12-PCS	11	46.7	±11.1	24.8	58.6
SF12-MCS	11	55.2	±7.5	41.2	63

3.2. Clinical Outcome Scores

The mean Foot Function Index (FFI) was 29.6 (±33.9). The lowest score, indicating no foot pain was 0, and the highest score was 79.4 (Table 3). For the SF-12 (Short Form-12 Version 2, SF-12v2), the mean score for the physical component (PCS) was 46.7 (±11.1); the lowest score recorded was 24.8 and the maximum recorded score was 58.6. The mean score for the mental component (MCS) was 55.2 (±7.5); the lowest score recorded was 41.2 and the maximum recorded score was 63.

3.3. Correlations between gait and functional outcome scores

The following relationships were strong and significant: EVGS and FFI (r=0.7; P=0.02), EVGS and the Physical Component Score (PCS) of the SF-12v2 (r=-0.82; P=0.02), and FFI and EQ5 (r=-0.79, P=0.05). There was no correlation demonstrated between the EVGS and the Mental Component Score (MCS) of the SF-12v2 (r=-0.1; P=1) (Table 4).

Table 4: Gait compared to outcome scores

	EVGS
FFI	r=0.7 (p=0.02)
SF12-PCS	r=-0.8 (p=0.02)
SF12-MCS	r=-0.1 (p=1)

4. Discussion

The most important finding of this study was that it demonstrated a strong and significant relationship between gait and foot pain, and as expected reduced gait quality was associated with residual foot pain. These findings are supported by a strong and significant association between gait and the physical component score (PCS) of the SF-12, whereas the mental component score (MCS) of the SF-12 did not demonstrate any significant relationship.

More than 90% of the abnormal gait parameters were observed in the foot. The two most common variables were reduced ankle dorsiflexion during both the stance and swing phase, and reduced hindfoot varus/valgus in stance. This finding could be the result of the original injury; initial treatment and/or management; post traumatic degeneration of the ankle due to a malaligned tibia; or treatment in the fixator used for correction of the malunion (26). Residual hindfoot disability and loss of motion has long been recognized as a consequence of tibial shaft fracture care (27). Long term joint immobilisation has previously been associated with changes in corticospinal excitability, which can result in musculotendinous stiffness and loss of motion (28). In the treatment of distal tibial fractures, a foot plate is often used to immobilise the ankle in a plantigrade position, possibly leading to Achilles tendon contractures (29). Limb deformities such as malunions result in uneven loading in the adjacent joints, presumably leading to accelerated cartilage wear and subsequent post-traumatic osteoarthritis (30,31). The closer a deformity is to a joint, the higher the incidence of osteoarthritis in the respective joint (26). This, in addition to joint stiffness from prolonged immobilisation, can potentially have a significant effect on gait and patient reported functional outcomes.

In a sophisticated study, Larsen et al investigated the relationships between gait and patient reported health related quality of life (HRQOL) in patients treated with intramedullary nailing for acute tibial shaft fractures (6). They demonstrated only weak associations between gait asymmetry and quality of life (6). These results are in contrast to our findings, but the two patient populations are perhaps not comparable. Although Larsen et al investigated the early outcomes in non-complicated acute tibial fractures in a healthy, young group of patients, most of the cohort investigated in this study were more complicated and underwent multiple surgical procedures for a chronic and more complicated condition. However, there are certainly similarities between the two studies (6). It appears that lower limb trauma results in gait abnormalities, and this effect is more prominent with more severe trauma. While minor gait abnormalities may not influence quality of life there is a positive correlation with patient reported outcome measures, and this assumption is supported by several studies (2, 6, 7, 11).

The ideal lower extremity alignment and the optimal degree of correction is currently unknown. Cho et al. suggested that valgus alignment of greater than 5 degrees is associated with increased foot progression and lateral rotation angles, and increasing knee adduction moments (32). Similarly, they suggested an overall tibiofemoral angle of less than 4 degrees varus was not associated with increased knee adduction moments. One could therefore safely assume that a tibial deformity should be corrected to a position of overall alignment between 5^0 valgus and 4^0 varus (32).

There is an obvious negative impact on mental health from major trauma (33,34). Posttraumatic stress disorder, depression, and psychological disorders are common complications observed in patients with these devastating injuries (33,34). Seven of the patients in this cohort sustained high-energy trauma, yet surprisingly the mental component score (MCS) of the SF-12 did not show any correlation with gait quality.

It may be that the protracted history and the resolution of their problem allowed these patients to have a more positive outlook. Unfortunately, the SF-12 was not used when the patients initially presented, but it is quite possible that the mental health scores would have been reduced at that time. This assumption is supported by the findings of Abulaiti et al, who reported on the negative impact that external fixation, circular external fixation in particular, has on patient mental health (33). Following removal of the fixator patients were still more satisfied following correction of their pathology and deformities.

Gait analysis requires dedication and considerable effort, which may not be possible during routine clinical practice (30). In particular, 3D gait analysis requires a high level of expertise, time commitment, and expensive equipment. Consequently, it is not always accessible, feasible, or practical for clinicians and researchers (4, 5). However, observation of gait forms an important aspect of the standard clinical examination for orthopaedic conditions, and is mainly based on visual observation (35). Simple video gait analysis (VGA) using a mobile phone is perhaps a relatively simple solution, and one that facilitates objective analysis of selected parameters such as joint flexion angles, cadence, and gait patterns. The VGA analysis technique is inexpensive, reproducible, and can be applied in clinical practice with minimal equipment and expertise. VGA has been well described in the literature for use in patients with hemiplegia, amputations, neurological diseases, cerebral palsy, rheumatoid arthritis, and spinal cord injuries, for both assessment and monitoring of treatment, but little has been described for patients with post-traumatic conditions (6, 23,30,35).

In an effort to make VGA more objective and reliable a number of observational gait scales have been developed such as the EVGS (28). In contrast to other systems, EVGS has demonstrated reliability and reproducibility when compared to 3DGA (22,23,36), and it is not limited by the ability to examine gait only in the sagittal plane. 3DGA allows for a more detailed analysis, but the addition of sophisticated video image analysis software, such as the Dartfish® application, improves accuracy and is reproducible and validated, as Borel et al. have demonstrated very high inter- and intra-observer levels of agreement (18).

This study is principally limited by the small sample size. Many of these patients were recruited from distant locations, and unable to return for further evaluation resulting in a lower than expected sample size. This was compounded by the long delay since their most recent follow-up. However, the length of the available follow-up, and the use of objective and subjective methods of assessing outcomes are strengths of the current study.

5. Conclusions

The results of this study suggest a relationship between gait and patient reported outcome measures. Simple methods of gait analysis can be used to monitor progress and assess patient outcomes following tibial fractures and malunions. Due to the simplicity and cost effectiveness of VGA combined with image software such as Dartfish®, we recommend its use as a monitoring and outcomes assessment tool in the management of orthopaedic trauma. The results of this study suggest that correction of deformity with realignment and restoration of normal anatomy was associated with improved functional outcomes and physical well-being. Patient reported quality of life was strongly associated with patient perceived functional outcome, but not with objective gait parameters.

Conflicts of interest statement

None.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

All authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

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