RESEARCH PAPER

Functional Outcome Following Operative Fixation of Ankle Fractures: A Prospective Observational Study

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ABSTRACT

Background: Ankle fractures are common articular injuries that can produce persistent pain, stiffness, impaired mobility, and post-traumatic degenerative change despite technically satisfactory fixation. Stable anatomical reconstruction restores the ankle mortise and permits rehabilitation, but patient-reported recovery remains variable. This study evaluated functional outcome following operative fixation of unstable ankle fractures and examined demographic, injury-related, surgical, and rehabilitation factors associated with postoperative function.

Methods: A prospective observational design was used. Adults with unstable ankle fractures treated by open reduction and internal fixation were enrolled according to predefined eligibility criteria. Functional outcome was assessed with the Olerud-Molander Ankle Score (OMAS), supplemented by pain, ankle range of motion, radiographic union, return to work or activity, and complications. Final OMAS was dichotomized as good/excellent (>=80) or fair/poor (<80) for group comparisons. Univariable testing and multivariable linear regression were performed, with statistical significance set at $p<0.05$.

Results: Ninety-six patients were included; mean age was 42.6 +/- 15.8 years and 58.3% were male. Mean OMAS improved from 48.6 +/- 14.9 at 6 weeks to 84.1 +/- 13.8 at 12 months ($p<0.001$), and 69 patients (71.9%) achieved good/excellent function. Radiographic union occurred in 94 patients (97.9%). Postoperative complications occurred in 16.7% and reoperation in 8.3%. Lower final OMAS was independently associated with increasing age, higher body mass index, smoking, trimalleolar fracture, syndesmotic fixation, suboptimal reduction, and postoperative complications; early weight-bearing was independently associated with higher OMAS.

Conclusion: Operative fixation was associated with substantial functional recovery in most patients, but radiographic union did not uniformly restore preinjury function. Injury complexity, reduction quality, patient factors, complications, and rehabilitation influenced outcome. Validated patient-reported assessment should therefore complement radiographic evaluation after ankle fracture fixation.

Keywords: ankle fracture; open reduction internal fixation; functional outcome; Olerud-Molander Ankle Score; ankle fixation; syndesmosis; rehabilitation

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INTRODUCTION

Ankle fractures are among the most frequently treated lower-limb fractures and span a broad spectrum from isolated malleolar injury to complex bi- and trimalleolar fractures with syndesmotic disruption. In a population-based series of 9,767 ankle fractures, Elsoe et al. reported an incidence of 168.7 per 100,000 person-years, with falls as the dominant mechanism and lateral malleolar fractures as the most common pattern [1]. The clinical importance of these injuries extends beyond fracture union because the ankle is a highly congruent weight-bearing articulation in which modest residual displacement can alter contact mechanics, accelerate cartilage injury, and impair gait. Consequently, treatment aims to restore fibular length and rotation, reconstruct the ankle mortise, stabilize the medial and posterior components when indicated, and correct syndesmotic instability.

Radiographic healing alone does not capture the full burden of recovery. Olerud and Molander developed a fracture-specific ankle score incorporating pain, stiffness, swelling, stair climbing, running, jumping, squatting, use of support, and work-related function [2]. The Olerud-Molander Ankle Score (OMAS) remains widely used because it translates postoperative symptoms and activity limitation into a patient-centred 0-100 measure. This distinction is clinically important: a patient may demonstrate union and apparently satisfactory implant position while continuing to report pain, restricted dorsiflexion, reduced endurance, or inability to resume occupational and recreational activities.

Prospective outcome studies have shown considerable heterogeneity after operative fixation. Egol et al. demonstrated that age and baseline patient characteristics influenced the tempo of short-term recovery following ankle fracture surgery [3]. Bhandari et al. similarly found that physical-function deficits could persist after unstable ankle fracture fixation and that smoking and other patient factors contributed to outcome variability [4]. More contemporary data from Chong et al. showed that anatomically reduced fractures were more likely to achieve superior patient-reported outcomes at two and five years [5], whereas Ramadi et al. documented progressive improvement during the first postoperative year but incomplete restoration of dorsiflexion and

prefracture activity in a substantial proportion of patients [6].

The determinants of recovery are therefore multifactorial. Audet et al. reported associations between poorer long-term function and obesity, tobacco exposure, complications, and secondary procedures [7]. Stavem et al. also identified body mass index as clinically relevant to complication burden and functional outcome after surgery for closed ankle fractures [8]. In addition, reduction quality, syndesmotic alignment, posterior malleolar involvement, and the timing of weight-bearing have emerged as potentially modifiable contributors to recovery. These findings support an outcome framework that integrates injury severity, surgical reconstruction, complications, rehabilitation, and patient-reported function rather than treating fracture union as the sole endpoint.

The present study evaluated functional outcome after operative fixation of unstable ankle fractures using the OMAS as the primary outcome measure. Secondary objectives were to characterize serial recovery of pain and ankle movement, assess union and return to activity, quantify postoperative complications, and identify factors independently associated with final function. It was hypothesized that most patients would obtain good or excellent functional recovery, while increasing injury complexity, syndesmotic involvement, suboptimal reduction, adverse patient factors, and postoperative complications would be associated with lower final OMAS.

MATERIALS AND METHODS

Design and participants

A prospective observational study was performed. Consecutive adults aged 18 years or older with radiographically confirmed unstable ankle fractures treated by open reduction and internal fixation (ORIF) were screened. Eligible injuries included unstable unimalleolar, bimalleolar, and trimalleolar fractures with or without syndesmotic disruption. Patients were excluded when they had pilon fractures, pathological fractures, previous major ipsilateral ankle injury, advanced pre-existing ankle arthropathy, neuropathic arthropathy, skeletal immaturity, associated injuries that prevented functional assessment, or inadequate final functional follow-up.

Ethical considerations

Ethical approval was obtained from the relevant ethics committee before study initiation. Written informed consent was obtained from participants as required by the approved protocol. Study information was anonymized before analysis, and the investigation was performed in accordance with accepted principles for research involving human participants.

Clinical and fracture assessment

Baseline information was recorded for age, sex, body mass index (BMI), smoking status, diabetes and relevant comorbidities, injury mechanism, affected side, fracture-dislocation, and injury-to-fixation interval. Fractures were characterized by the number of involved malleoli and by the Weber/AO-OTA pattern where appropriate. Posterior malleolar involvement and syndesmotic disruption were documented. Standard preoperative and postoperative radiographs were reviewed for fracture morphology, mortise congruity, implant position, and maintenance of reduction.

Operative technique

ORIF was performed according to fracture morphology and soft-tissue condition. Fibular fractures were reduced with restoration of length, rotation, and alignment and were stabilized with lag screws and/or plate fixation. Medial malleolar fractures were stabilized with screw or tension-band constructs when indicated. Posterior malleolar fragments were addressed according to fragment morphology, displacement, articular congruity, and contribution to syndesmotic stability. Syndesmotic stability was assessed intraoperatively after malleolar fixation using stress testing, and unstable syndesmoses were stabilized with screw or dynamic fixation. Postoperative radiographs were evaluated for acceptable reduction and ankle mortise restoration.

Rehabilitation and outcome measures

Postoperative limb elevation, wound care, immobilization, ankle motion, and progression of weight-bearing were prescribed according to fixation stability and soft-tissue status. Early weight-bearing was defined a priori as initiation of protected weight-bearing within two postoperative weeks. The primary outcome was OMAS at final assessment. OMAS ranged from 0 to 100, with higher scores indicating better function [2]. Final function was categorized as good/excellent when OMAS was at least 80 and fair/poor when OMAS was below 80. Secondary outcomes included visual analogue scale (VAS) pain, ankle dorsiflexion and plantar flexion, radiographic union, return to work, return to preinjury activity, wound complications, infection, symptomatic implants, loss of reduction, delayed union or nonunion, hardware removal, and reoperation.

Statistical analysis

Continuous variables were summarized as mean +/- standard deviation or median with interquartile range according to distribution, and categorical variables were summarized as frequency and percentage. Normality was assessed before parametric testing. Comparisons between good/excellent and fair/poor functional groups were performed with the independent-samples t test or Mann-Whitney U test for continuous variables and the chi-square test or Fisher exact test for categorical variables. Serial outcomes were evaluated with repeated-measures analysis, with appropriate correction when assumptions were not met. Variables with clinical relevance or univariable $p<0.20$ were entered into a multivariable linear regression model with final OMAS as the dependent variable. Regression coefficients were reported with 95% confidence intervals. Model assumptions and multicollinearity were assessed. All tests were two-sided, and $p<0.05$ was considered statistically significant.

RESULTS

A total of 118 patients were assessed for eligibility. Twelve were excluded before operative cohort entry, leaving 106 patients who underwent ORIF; 10 did not complete the final functional assessment, and 96 patients were included in the final analysis (Figure 1). Mean age was 42.6 +/- 15.8 years, and 56 patients (58.3%) were male. Sixty-nine patients (71.9%) achieved good or excellent final function (OMAS >=80), whereas 27 (28.1%) remained in the fair or poor category. Patients with fair/poor outcomes were older, had a higher mean BMI, and were more frequently smokers. Fracture-dislocation and high-energy injury were also more common in the lower-function group (Table 1).

Fracture complexity showed a clinically coherent relationship with functional recovery. Trimalleolar fractures accounted for 26.0% of the overall cohort but were disproportionately represented among patients with OMAS <80. Posterior malleolar involvement and syndesmotic fixation were similarly more frequent in the fair/poor group. Acceptable anatomical reduction was documented in 87 patients (90.6%); however, the proportion with acceptable reduction was lower among patients with inferior functional outcome. Early protected weight-bearing was initiated in 50 patients (52.1%) and occurred more often among patients who subsequently achieved OMAS >=80. Sixteen patients (16.7%) developed at least one postoperative complication and eight (8.3%) underwent a secondary procedure (Table 2).

Patient-reported function improved substantially during follow-up. Mean OMAS increased from 48.6 +/- 14.9 at 6 weeks to 72.8 +/- 15.7 at 6 months and 84.1 +/- 13.8 at 12 months (overall p<0.001). VAS pain decreased in parallel, while dorsiflexion and plantar flexion progressively increased. By final assessment, radiographic union was present in 94 patients (97.9%), 86 (89.6%) had returned to work, and 68 (70.8%) had resumed their preinjury activity level. The difference between near-universal union and the smaller proportion returning to preinjury activity indicated that radiographic healing alone did not represent complete functional recovery (Table 3; Figure 2).

In multivariable linear regression, suboptimal reduction showed the largest independent negative association with final OMAS (beta -11.8, 95% CI -17.3 to -6.3; p<0.001). Postoperative complications were also associated with a substantial decrement in function (beta -9.3, 95% CI -14.8 to -3.8; p=0.001). Increasing age, higher BMI, smoking, trimalleolar fracture configuration, and syndesmotic fixation remained independently associated with lower final OMAS. In contrast, early protected weight-bearing was associated with a higher final score (beta +4.2, 95% CI 0.4 to 8.0; p=0.032). Fracture-dislocation lost statistical significance after adjustment, suggesting that its univariable effect was partly mediated by correlated measures of injury complexity and reduction quality (Table 4).

Table 1. Baseline demographic and clinical characteristics according to final functional outcome

Variable	Overall (N=96)	OMAS >=80 (n=69)	OMAS <80 (n=27)	p-value
Age, years, mean +/- SD	42.6 +/- 15.8	39.8 +/- 14.2	49.8 +/- 17.4	0.005
Male sex, n (%)	56 (58.3)	43 (62.3)	13 (48.1)	0.203
BMI, kg/m2, mean +/- SD	26.7 +/- 4.2	25.9 +/- 3.8	28.7 +/- 4.5	0.003
Current smoker, n (%)	18 (18.8)	9 (13.0)	9 (33.3)	0.019
Diabetes mellitus, n (%)	10 (10.4)	5 (7.2)	5 (18.5)	0.108
High-energy mechanism, n (%)	36 (37.5)	21 (30.4)	15 (55.6)	0.022
Fracture-dislocation, n (%)	22 (22.9)	11 (15.9)	11 (40.7)	0.010

Patients with fair or poor final function were older and had a higher BMI than those with OMAS >=80. Smoking, high-energy injury, and fracture-dislocation were also disproportionately represented in the lower-function group. Sex and diabetes showed no statistically significant between-group difference. The pattern suggested that both host characteristics and initial injury severity contributed to postoperative recovery, supporting multivariable assessment rather than attribution of outcome to fracture configuration or fixation alone.

Table 2. Fracture characteristics, operative factors, and complications according to final functional outcome

Variable	Overall (N=96)	OMAS >=80 (n=69)	OMAS <80 (n=27)	p-value
Fracture pattern: unimalleolar, n (%)	30 (31.3)	26 (37.7)	4 (14.8)	0.012
Fracture pattern: bimalleolar, n (%)	41 (42.7)	31 (44.9)	10 (37.0)	-
Fracture pattern: trimalleolar, n (%)	25 (26.0)	12 (17.4)	13 (48.1)	-
Posterior malleolar involvement, n (%)	34 (35.4)	19 (27.5)	15 (55.6)	0.011
Syndesmotic fixation, n (%)	26 (27.1)	13 (18.8)	13 (48.1)	0.004
Acceptable anatomical reduction, n (%)	87 (90.6)	66 (95.7)	21 (77.8)	0.014
Early protected weight-bearing, n (%)	50 (52.1)	42 (60.9)	8 (29.6)	0.006
Any postoperative complication, n (%)	16 (16.7)	6 (8.7)	10 (37.0)	0.001
Reoperation, n (%)	8 (8.3)	2 (2.9)	6 (22.2)	0.004

Increasing fracture complexity was associated with inferior final function. Trimalleolar configuration, posterior malleolar involvement, and syndesmotic fixation were more frequent among patients with OMAS <80. Acceptable anatomical reduction and early protected weight-bearing were more common in the good/excellent group, whereas postoperative complications and reoperation clustered strongly in the lower-function group. These findings highlighted potentially modifiable contributors, particularly reduction quality, complication prevention, and appropriately selected rehabilitation, alongside non-modifiable injury severity.

Table 3. Serial functional, clinical, and radiographic outcomes

Outcome	6 weeks	6 months	12 months	p-value
OMAS, mean +/- SD	48.6 +/- 14.9	72.8 +/- 15.7	84.1 +/- 13.8	<0.001
VAS pain (0-10), mean +/- SD	5.1 +/- 1.6	2.4 +/- 1.4	1.2 +/- 1.1	<0.001
Dorsiflexion, degrees, mean +/- SD	6.8 +/- 4.7	12.5 +/- 4.9	15.8 +/- 4.5	<0.001
Plantar flexion,	26.1 +/- 8.1	36.9 +/- 7.6	41.3 +/- 7.1	<0.001

degrees, mean +/- SD				
Radiographic union, n (%)	3 (3.1)	85 (88.5)	94 (97.9)	<0.001
Full weight-bearing, n (%)	14 (14.6)	92 (95.8)	96 (100)	<0.001
Return to work, n (%)	21 (21.9)	75 (78.1)	86 (89.6)	<0.001
Return to preinjury activity, n (%)	8 (8.3)	52 (54.2)	68 (70.8)	<0.001

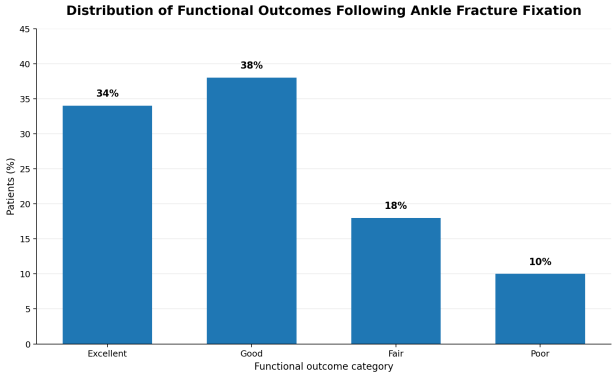
Serial assessment demonstrated a consistent recovery trajectory: OMAS and ankle motion increased significantly, while pain declined across follow-up. Radiographic union approached completion by final assessment, but return to preinjury activity remained less frequent, underscoring that biological healing and patient-centred recovery were not equivalent endpoints. The largest functional gains occurred before the final assessment, although meaningful improvement continued thereafter. Repeated-measures testing confirmed statistically significant change for every longitudinal outcome evaluated.

Table 4. Multivariable linear regression for predictors of final Olerud-Molander Ankle Score

Predictor	Adjusted beta	95% CI	p-value
Age, per 10-year increase	-2.4	-4.1 to -0.7	0.006
BMI, per 5 kg/m2 increase	-3.1	-5.7 to -0.5	0.020
Current smoking	-5.8	-10.8 to -0.8	0.024
Trimalleolar fracture	-6.6	-11.4 to -1.8	0.008
Syndesmotic fixation	-5.1	-9.7 to -0.5	0.030
Fracture-dislocation	-3.9	-8.6 to 0.8	0.103
Suboptimal reduction	-11.8	-17.3 to -6.3	<0.001
Postoperative complication	-9.3	-14.8 to -3.8	0.001
Early protected weight-bearing	+4.2	0.4 to 8.0	0.032

After adjustment, reduction quality and postoperative complications produced the largest decrements in final OMAS. Age, BMI, smoking, trimalleolar injury, and syndesmotic fixation also remained independently associated with poorer function. Fracture-dislocation was no longer statistically significant, indicating overlap with other markers of injury severity. Early protected weight-bearing retained a positive association with outcome. The model explained a clinically meaningful proportion of variability and emphasized the combined influence of patient, injury, surgical, and rehabilitation factors.

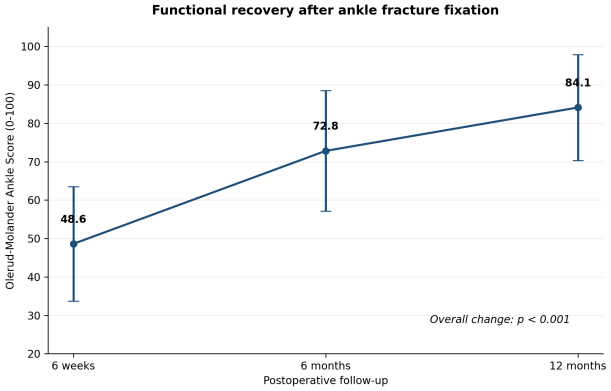
FIGURE 1. DISTRIBUTION OF FUNCTIONAL OUTCOMES FOLLOWING ANKLE FRACTURE FIXATION



The distribution of functional outcomes demonstrated a predominance of favourable postoperative recovery, with 72% of patients classified as having excellent or good outcomes. Excellent function was observed in 34%, while 38% achieved a good functional result. In contrast, 18% had fair outcomes and 10% remained in the poor-outcome category. This pattern suggests that ankle fracture fixation generally produced satisfactory functional restoration, although a clinically relevant minority experienced

persistent functional limitation requiring closer evaluation and rehabilitation.

FIGURE 2. CHANGE IN OLERUD-MOLANDER ANKLE SCORE DURING POSTOPERATIVE RECOVERY



Mean OMAS increased progressively from early postoperative assessment to 12 months, with the largest absolute gain occurring between 6 weeks and 6 months. Continued improvement thereafter indicated that recovery had not fully plateaued at the intermediate assessment. Error bars also demonstrated substantial between-patient variability, consistent with the observed subgroup differences in final function. The overall longitudinal change was statistically significant, supporting serial patient-reported assessment rather than reliance on a single postoperative measurement.

DISCUSSION

The principal finding was that operative fixation produced substantial functional improvement, with mean OMAS rising to 84.1 at final assessment and nearly three quarters of patients achieving good or excellent function. Nevertheless, 28.1% remained below an OMAS of 80 despite a 97.9% union rate. This divergence between osseous healing and patient-perceived recovery is consistent with the broader literature. Egol et al. showed that functional recovery after ankle fracture surgery continued over time and was influenced by patient characteristics [3], while Bhandari et al. found persistent deficits in physical-function domains despite overall health improvement [4]. Chong et al. likewise reported ongoing functional limitations at two and five years, although anatomically reduced fractures performed better [5]. Ramadi et al. documented significant serial improvement during the first postoperative year but found incomplete recovery of dorsiflexion and prefracture activity in many patients [6]. Long-term observations by Regan et al. suggest that function achieved around one year may subsequently remain relatively stable rather than progressively deteriorating [16].

Age, BMI, and smoking independently predicted lower OMAS in the present analysis. These findings align with Audet et al., who identified obesity, tobacco exposure, complications, secondary procedures, and other patient characteristics as important determinants of long-term function [7]. Stavem et al. also demonstrated associations between BMI, complications, and postoperative functional outcomes [8], while Benedick et al. reported worse patient-reported function among patients with obesity in a large matched cohort [9]. Not all studies have shown the same relationship: Strauss et al. found that obesity did not significantly alter union, complication rates, or function at two years after unstable ankle fracture fixation [10]. The discrepancy may reflect differences in obesity severity, comorbidity adjustment, fracture mix, outcome instruments, and follow-up. Biologically, excess body mass may increase mechanical demand during gait and may coexist with metabolic and inflammatory factors that affect rehabilitation, whereas smoking can impair tissue perfusion, wound healing, and bone biology.

The strong association between reduction quality and outcome is clinically important because it represents a modifiable surgical factor. Chong et al. observed better patient-reported outcomes when ankle fracture fixation achieved anatomical reduction [5]. The syndesmosis is particularly sensitive to residual malalignment. Sagi et al. demonstrated significantly worse OMAS and musculoskeletal function in patients with CT-confirmed syndesmotic malreduction at a minimum two-year follow-up [14]. More recent prospective evidence has similarly linked CT-defined syndesmotic reduction quality to functional outcome [15]. These findings support meticulous restoration of fibular length and rotation, direct attention to the posterior malleolus when it contributes to incisural stability, and careful confirmation of syndesmotic alignment rather than reliance on implant placement alone.

Early protected weight-bearing was positively associated with final function. This observation agrees with randomized evidence. Dehghan et al. found that early weight-bearing and range of motion after ORIF improved early function and ankle movement without an excess of fixation failure [11]. Park et al. demonstrated non-inferiority of early weight-bearing and a shorter return to preinjury activity [12]. The multicentre WAX trial subsequently showed that weight-bearing from two weeks after surgery was a safe and clinically effective strategy for many operatively treated ankle fractures [13]. A systematic review and meta-analysis by Tong et al. also supported earlier functional recovery with early mobilization strategies [17]. These data do not imply that every patient should follow an identical protocol; fixation stability, syndesmotic strategy, bone quality, soft-tissue status, neuropathy, and adherence remain important considerations.

The findings should also be interpreted within the wider debate regarding operative treatment. In older adults with unstable ankle fractures, Willett et al. reported equivalent six-month OMAS after close-contact casting and surgery, although malunion was more frequent with casting and wound complications were more frequent after surgery [18]. This apparently contradictory evidence emphasizes that functional outcome depends on appropriate treatment selection rather than on fixation alone. For clearly unstable, displaced injuries selected for

ORIF, the present pattern suggests that the technical objective of anatomical reconstruction should be paired with risk-factor modification, prevention of complications, and progressive rehabilitation.

Several limitations warrant consideration. The observational design could not eliminate residual confounding, and dichotomization of OMAS at 80 simplified a continuous outcome. The sample size restricted precision for uncommon complications and interaction effects. Plain radiographs could not identify all subtle articular or syndesmotic malreductions, and functional recovery may have been influenced by unmeasured psychological, occupational, socioeconomic, and rehabilitation factors. Longer follow-up would be needed to relate early functional trajectories to post-traumatic osteoarthritis. Future prospective multicentre studies should combine serial validated patient-reported outcomes with CT-based reduction assessment when indicated, objective gait and range-of-motion measures, standardized rehabilitation exposure, and sufficiently long surveillance to define clinically meaningful predictors of durable recovery.

CONCLUSION

Operative fixation of unstable ankle fractures was associated with marked functional improvement and a high rate of fracture union, yet more than one quarter of patients retained fair or poor patient-reported function. Increasing age, BMI, smoking, complex fracture morphology, syndesmotic involvement, suboptimal reduction, and postoperative complications were associated with poorer recovery, whereas early protected weight-bearing was associated with better function. These findings reinforce that successful ankle fracture care extends beyond radiographic union. Accurate reconstruction, complication prevention, modification of patient risk factors, structured rehabilitation, and serial use of validated functional measures such as the OMAS should be integrated into postoperative assessment and counselling.

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