Introduction


One way to classify the severity of ankle fracture is by the number of malleoli involved, ie, unimalleolar, bimalleolar or trimalleolar fracture (Donatto 2001, Michelson 1995). It has been found that those with unimalleolar fractures report less activity limitation than those with bimalleolar or trimalleolar fractures (Beris et al 1997, Broos and Bisschop 1991, Hancock et al 2005, Kennedy et al 1998). But this needs further validation as some of the studies used retrospective data collection and had a significant (> 35%) loss to follow-up (Beris et al 1997, Kennedy et al 1998). The fractured ankle is usually immobilised for approximately six
weeks after orthopaedic reduction of the fracture (Donatto 2001, Lesic and Bumbasirevic 2004). Animal studies have demonstrated that immobilisation causes muscle shortening (Herbert and Balnave 1993, Herbert and Crosbie 1997), and that immobilising the ankle in a more plantarflexed position causes a greater reduction in calf muscle length than does immobilisation in a more dorsiflexed position (Herbert and Balnave 1993, Tabary et al 1972). But the relationship between the angle of immobilisation and outcome after ankle fracture has not been investigated in humans.

Clinical observation suggests that the initial recovery from ankle fracture occurs quickly in the first few days following cast removal. Patients assessed immediately following cast removal can be expected to perform more poorly than patients assessed several days following cast removal. Consequently the timing of baseline assessment before physiotherapy intervention may influence eventual clinical outcomes. But this has not been validated.

Literature on the predictors of outcome after ankle fracture focuses on variables that are related to the injury (‘injury-related variables’), such as fracture severity and management. By comparison, relatively little is known about the influence of variables that are related to patients’ performance (‘performance-related variables’), such as pain or mobility. Clinical measures that are commonly used to monitor progress after ankle fracture include activity limitation, pain, mobility, and ankle range of motion. Of these, only the predictive value of ankle dorsiflexion has been investigated. Decreased dorsiflexion at the time of cast removal was associated with increased activity limitation in the short-and medium-term ($r^2 > 0.16$) (Hancock et al 2005). Therefore, the specific research question investigated in this study was:

What is the predictive value of injury-related and performance-related variables on activity limitation 4 and 12 weeks after cast removal for ankle fracture in people receiving physiotherapy intervention?

**Method**

**Design**

Data collected in two randomised trials conducted by the authors were used (Lin et al 2008, Moseley et al 2005). Data from one trial (Moseley et al 2005) were used to derive the predictive value of the variables investigated, and to formulate a clinical prediction rule (the ‘derivation study’). In this trial, participants received one of three interventions: long-duration stretch plus exercise, short-duration stretch plus exercise, or exercise-only interventions from their physiotherapist over four weeks. Participants were followed up at 4 and 12 weeks by an assessor who was a registered physiotherapist and blinded to group allocation. No statistically- or clinically-significant differences in outcomes between groups receiving the three interventions were found. The clinical prediction rule was validated using data from the other trial (the ‘validation study’) (Lin et al 2008). In this trial, participants received either joint mobilisation plus exercise or exercise only over four weeks. Participants were followed up at 4, 12, and 24 weeks by an assessor who was a registered physiotherapist and blinded to group allocation. No statistically- or clinically-significant differences in outcomes between groups receiving the two interventions were found.

**Participants**

Both trials recruited participants from the physiotherapy departments of teaching hospitals in Sydney, Australia. In the derivation study (Moseley et al 2005), adult participants were recruited within five days of cast removal if they met the inclusion criteria: ankle fracture treated with cast immobilisation with or without surgical fixation, approval from the orthopaedic specialist to weight-bear as tolerated or partial weight-bear, no significant concurrent injuries or pathologies which may affect the recovery of lower limb function, reduced passive dorsiflexion (at least 5 degrees less than the unaffected ankle), and referral to outpatient physiotherapy.

In the validation study (Lin et al 2008), adult participants fulfilling the following criteria were recruited within seven days of cast removal: ankle fracture treated with cast immobilisation with or without surgical fixation, approval from the orthopaedic specialist to weight-bear as tolerated or partial weight-bear, no significant concurrent injuries or pathologies which may affect the recovery of lower limb function, a pain score of at least 2 out of 10 (Numerical Rating Scale) in the ankle on equal weight-bearing, and referral to outpatient physiotherapy.

**Outcome measures**

The predictors consisted of four injury-related variables (fracture management, fracture severity, angle of immobilisation, and time from cast removal to baseline assessment) and four performance-related variables (activity limitation, pain, mobility, and ankle dorsiflexion) measured within one week of cast removal and before the

![Figure 1. The angle of immobilisation was measured as the angle between the mid shaft of tibia and a line connecting the anterior-superior point (A) and posterior-superior point (B) of the calcaneus. The angle at the anterior-inferior corner (C) was used, so a larger angle denotes more dorsiflexion.](image-url)
start of physiotherapy. Fracture management (surgical or conservative) was ascertained by interviewing participants and confirmed by hospital records. Fracture severity was classified according to the number of malleoli involved (unimalleolar, bimalleolar, or trimalleolar) by viewing plain radiographs of the fracture or, if radiographs were not available, according to orthopaedic or radiology entries in the hospital records. The angle of immobilisation was calculated using the lateral-view radiographs of the ankle taken during cast immobilisation (Figure 1). Because participants in both the derivation (Moseley et al 2005) and validation (Lin et al 2008) studies were measured any time within one week of cast removal, time from cast removal to baseline assessment was examined for its predictive value.

Activity limitation was measured using the Lower Extremity Functional Scale (Binkley et al 1999) where self-reported activity limitation on 20 activities is scored out of 80. A higher score indicates less activity limitation. It has high internal consistency (alpha = 0.96) and test-retest reliability (ICC = 0.86), and correlates well with the physical component of the Short Form 36 Health Survey (Binkley et al 1999). Pain in the fractured ankle was rated on a 100-mm visual analogue scale (Kahl and Cleland 2005, von Korff et al 2000) while participants stood bearing weight equally through the fractured and non-fractured sides. The participants’ ability to walk 10 m without a walking aid was used as a measure of mobility. This was dichotomised as ‘Yes’ (able to walk 10 m without aid) or ‘No’ (unable to walk 10 m without aid). In the derivation study (Moseley et al 2005), dorsiflexion was measured in degrees using the Lidcombe template (Moseley and Adams 1991). In the validation study (Lin et al 2008), dorsiflexion was measured as distance in centimetres using the weight-bearing lunge method (Bennell et al 1998) converted to degrees using anthropometric data (Winter 1990) and trigonometry. Both the Lidcombe template and the weight-bearing lunge method have high interrater reliability (Bennell et al 1998, Moseley and Adams 1991).

The dependent outcome was activity limitation measured on the Lower Extremity Functional Scale (Binkley et al 1999) at 4 and 12 weeks after randomisation. Baseline data were not consulted during the measurement at 4 and 12 weeks.

### Data analysis
Because there were no between-group differences in outcomes in either the derivation (Moseley et al 2005) or validation (Lin et al 2008) study, data from the entire cohort in each study were used. Data from the derivation study (Moseley et al 2005) were analysed first with univariate linear regression. The significant predictors (p ≤ 0.20 at either 4 or 12 week follow-up) were then entered into a multivariate linear model using the ‘xtreg’ procedure in STATA v8. Time of follow-up (ie, 4 weeks or 12 weeks) was treated as a dichotomous variable and dummy coded as two fixed variables. Separate analyses were conducted for each of the predictor variables using a forward stepwise procedure. We used chi-square tests to determine whether variables contributed significantly to the model (p < 0.05). Fracture management (surgical or conservative), fracture severity (unimalleolar or bimalleolar/trimalleolar), and mobility (able to walk 10 m unaided, Yes or No) were
entered into the model as dichotomous variables. The angle of immobilisation, baseline activity limitation, pain, and dorsiflexion were entered into the model as continuous variables. The resulting model was simplified by rounding the coefficients to make a simple clinical prediction rule. The accuracy of the prediction rule was validated by comparing the outcomes generated by the clinical prediction rule to the actual outcomes of the validation study (Lin et al 2008).

Results
Characteristics of participants
In the derivation study (Moseley et al 2005), participant recruitment (n = 94) and follow-up occurred between May 2000 and July 2003. In the validation study (Lin et al 2008), participant recruitment (n = 150) and follow-up occurred between October 2004 and January 2007. Characteristics of the participants are presented in Table 1. Complete data were available at assessment time points (ie, baseline and 4 and 12 week follow-up) for 95% of participants in the derivation study (Moseley et al 2005) and 98% of participants in the validation study (Lin et al 2008) (see Figure 2).

Derivation of the clinical prediction rule
In the univariate analyses, fracture management, fracture severity, baseline activity limitation, pain, mobility, and dorsiflexion predicted activity limitation at 4 or 12 weeks after cast removal (p ≤ 0.20, Table 2). Variables that were injury-related (ie, fracture management and fracture severity; r² = 0.01 to 0.07) were weaker predictors than variables that were performance-related (ie, baseline activity limitation, pain, mobility, and dorsiflexion ROM; r² = 0.06 to 0.27). The angle of immobilisation and time from cast removal did not significantly predict activity limitation at 4 or 12 weeks (p > 0.20) and were omitted from the multivariate analysis.

In the multivariate analysis, the only significant independent predictors of activity limitation were pain and dorsiflexion. The following models including these predictors explained approximately 15% of the variance in the Lower Extremity Functional Scale (LEFS) at 4 (r² = 0.16, Box 1) and 12 weeks (r² = 0.15, Box 2) of the derivation study.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Activity limitation at 4 weeks</th>
<th>Activity limitation at 12 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression coefficients</td>
<td>Significance</td>
</tr>
<tr>
<td>Injury-related</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture management</td>
<td>–6.74 (–11.25 to –2.26)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Fracture severity</td>
<td>7.18 (–11.80 to –2.56)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Angle of immobilisation</td>
<td>–0.20 (–0.17 to 0.56)</td>
<td>0.29</td>
</tr>
<tr>
<td>Time from cast removal to baseline</td>
<td>–0.49 (–2.49 to 0.63)</td>
<td>0.24</td>
</tr>
<tr>
<td>Performance-related</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>–0.20 (–0.30 to –0.11)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>0.38 (0.16 to 0.59)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Mobility</td>
<td>10.09 (5.28 to 14.90)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Baseline activity limitation</td>
<td>0.59 (0.43 to 0.76)</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

For ease of application in a clinical situation, the models were simplified by rounding the coefficients to the following clinical prediction rules:

LEFS at 4 weeks = 28.8 (constant) + 24.8 (time of follow-up) – 0.21 × pain + 0.20 × dorsiflexion

LEFS at 12 weeks = 28.8 (constant) + 37.7 (time of follow-up) – 0.21 × pain + 0.20 × dorsiflexion

For example, the average participant in the derivation study (Moseley et al 2005) had a pain score of 17 mm on a 100 mm visual analogue scale and dorsiflexion of 7 degrees at baseline assessment. This would mean that the predicted score on the LEFS would be 53 out of 80 (ie, 55 – 17/5 + 7/5) at 4 weeks and 63 out of 80 (ie, 65 – 17/5 + 7/5) at 12 weeks.

Validation of the clinical prediction rule
The amount of variance in outcome explained by the clinical prediction rules was identical to that of the models prior to rounding. When applied to an independent sample in the validation study (Lin et al 2008), the rules were able to explain a small amount of variance in activity limitation at 4 (r² = 0.12) and 12 weeks (r² = 0.09).
Regression coefficients of predictors

<table>
<thead>
<tr>
<th>Constant</th>
<th>Time of follow-up (fixed variable)</th>
<th>Pain</th>
<th>Dorsiflexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.8</td>
<td>24.8 (26.7 to 30.8)</td>
<td>-0.21 (-0.28 to -0.14)</td>
<td>0.20 (0.05 to 0.35)</td>
</tr>
</tbody>
</table>

Clinical prediction rule

Activity limitation = 28.8 (constant) + 24.8 (time of follow-up) - 0.21 (pain) + 0.20 (dorsiflexion)

Accuracy of prediction

\[ r^2 = 0.15 \]

Discussion

Our study showed that performance-related variables were stronger predictors of short- and medium-term activity limitation than injury-related variables in people receiving physiotherapy intervention after ankle fracture. Only pain and dorsiflexion measured within one week of cast removal were independent predictors of activity limitation. A clinical prediction rule consisting of pain and dorsiflexion explained 12% and 9% of the variance and activity limitation in an independent sample four and 12 weeks later.

The univariate predictive value of fracture management was negligible, and similar in magnitude to a previous study (Hancock et al. 2005). Studies investigating the predictive value of fracture management differ in their findings of whether surgical or conservative management predicts less activity limitation (Hancock et al. 2005, Lash et al. 2002, Makwana et al. 2001, Phillips et al. 1985, Rowley et al. 1986). Our results, together with the inconsistent findings of these studies, suggest that fracture management is not a reliable predictor of activity limitation after ankle fracture.

This was the first study of outcomes after ankle fracture that sought to validate predictors in an independent sample. External validation of the clinical prediction rule showed that the rule was a weak predictor of activity limitation. This means that while the rule may be used clinically to...
predict short- to medium-term activity limitation, most of the variance predicting activity limitation is as yet unknown. Other than fracture management, fracture severity, and ankle dorsiflexion, we did not investigate factors that may predict activity limitation based on previous research due to the constraint of the sample size. There is weak evidence from previous research in ankle fracture suggesting that female gender (Belcher et al. 1997, Egol et al. 2006, Lindsjo 1985), inadequate fracture reduction (Beris et al. 1997, Lindsjo 1985, Weening and Bhandari 2005), medial malleolar fracture (Broos and Bisschop 1991), posterior malleolar fracture (Broos and Bisschop 1991, Lash et al. 2002, Lindsjo 1985), older age (Egol et al. 2006, Kennedy et al. 1998, Shah et al. 2007), or greater fracture displacement (Kennedy et al. 1998) are associated with increased activity limitation after ankle fracture. Some of these factors may account for the variance not captured by our clinical prediction rule. However, while previous studies have focused on the predictive value of injury-related variables, our finding of the higher predictive value of performance-related variables compared with injury-related variables suggests that future research should further explore the predictive value of other performance-related variables, eg. strength.

Similar to our results, findings from studies on predictors of outcome in multi-trauma indicate that injury-related variables, such as injury severity, are not reliable predictors of ongoing disability (Harris et al. 2008, Ponsford et al. 2008). In contrast, numerous non-injury related variables, including socioeconomic status, social support, and compensable status, are significantly related to ongoing disability after trauma (Harris et al. 2008, Mock et al. 2000). These non-injury-related variables may also account for some of the variance not captured by our clinical prediction rule in people with ankle fracture.

One limitation of this investigation was that it was based on secondary analyses of data collected from previous studies rather than from a cohort chosen to answer this specific research question, and we did not investigate the influence of predictors on long-term outcome. In addition, we recruited our cohort from physiotherapy departments, which may limit the generalisability of the study findings to the subset of people receiving physiotherapy intervention after ankle fracture. The amount of variance explained by our prediction rule is similar to the only other study that has investigated the association of multiple variables with outcomes after ankle fracture (Hancock et al. 2005). This other study recruited their cohort from orthopaedic clinics and showed that of the variables investigated (fracture management, fracture severity, ankle dorsiflexion, age) dorsiflexion was the only variable that independently predicted activity limitation in both the short- and medium-term. Pain was not investigated as a potential predictor and the model has not been validated.

Our study suggests that in people receiving physiotherapy intervention after ankle fracture, performance-related variables are stronger predictors of short- and medium-term activity limitation than injury-related variables. Pain and dorsiflexion within one week of cast removal are independent predictors, but the resultant clinical prediction rule explains only a small variance in outcomes. Nonetheless, our prediction rule provides the only validated data to date that may assist clinicians in providing information on prognosis to patients. The prediction rule suggests that patients with more pain and less dorsiflexion after cast removal will have more limitation in activity in the short-to medium-term. Tailoring intervention to these impairments may improve their prognosis. This may involve appropriate pain relief, or selectively allocating more rehabilitation sessions to this subgroup of patients.

Footnote: *StataCorp LP, 4905 Lakeway Drive, College Station, Texas 77845, USA.

Ethics: The University of Sydney Human Research Ethics Committee, Northern Sydney and Central Coast Research Office, Sydney South West Area Health Service Ethics Review Committee (RPAH zone), and the St Vincent’s Hospital Research Office approved this study. Written informed consent was gained from all participants before data collection began.

Competing interests: None declared.

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