

# Dynamic Splinting for the Stiff Hand after Trauma: Predictors of Contracture Resolution

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During 2004–2005, injuries to the wrist and hand were the second most common injuries requiring hospital admission in Australia, accounting for 13.3%.<sup>1</sup> The Australian Safety and Compensation Council<sup>2</sup> found that the most common area of the body to result in a serious worker's compensation claim during the period 2005–2006 was the upper limb, at 31%. Injuries specifically involving the hand accounted for 13% of all claims.

Joint contracture is a common secondary complication after traumatic hand injury.<sup>3–10</sup> The loss of active range of motion (AROM) and passive range

## ABSTRACT:

**Study Design:** Prospective cohort.

**Introduction:** Many variables are believed to influence the success of dynamic splinting, yet their relationship with contracture resolution is unclear.

**Purpose of the Study:** To identify the predictors of outcome with dynamic splinting of the stiff hand after trauma.

**Methods:** Forty-six participants (56 joints) completed eight weeks of dynamic splinting, and the relationship between 13 clinical variables and outcome was explored.

**Results:** Improvement in passive range of motion, active range of motion (AROM), and torque range of motion averaged 21.8°, 20.0°, and 13.0°, respectively (average daily total end range time, 7.96 hours). Significant predictors included joint stiffness (modified Weeks Test), time since injury, diagnosis, and deficit (flexion/extension). For every degree change in ROM on the modified Weeks Test, AROM improved 1.09° (standard error, 0.2). Test–retest reliability of the modified Weeks Test was high (intraclass correlation coefficient [2, 1] = 0.78).

**Conclusions:** Better progress with dynamic splinting may be expected in joints with less pretreatment stiffness, shorter time since injury (<12 weeks), and in flexion rather than extension deficits. Further research is needed to determine the accuracy with which the modified Weeks Test may predict contracture resolution.

**Level of Evidence:** 2b.

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of motion (PROM) resulting from joint contracture impacts significantly on the use of the hand in daily tasks, such as dressing, eating, or work-related activities.<sup>10</sup> Consequently, hand therapists are frequently challenged with the task of improving range of motion (ROM) to facilitate restoration of function after hand trauma.<sup>8</sup> Splinting is a common treatment modality used to achieve this in the presence of joint contracture.<sup>11–14</sup>

Dynamic splints are comprised of a stable static base and an elastic mobilizing component. The mobilizing component is made from a range of dynamic materials that may include elastic bands, springs, coils, or lycra.<sup>14</sup> Dynamic splints hold the stiff joint/joints at the end of available ROM, under light tension, for extended periods of time. Subsequent growth and reorganization of collagen fibers in the soft tissues involved in the contracture allows for increased PROM.<sup>14–20</sup>

Many factors are believed to influence the success of dynamic splinting in contracture resolution, including the degree of pretreatment joint stiffness, diagnosis, time since injury, age, gender, insurance

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status, and joint type.<sup>14,21,22</sup> For example, poorer progress with splinting treatment may be expected if the patient is elderly and it is quite some time since the original injury. The proximal phalangeal (PIP) joint is often felt to be more troublesome than the metacarpophalangeal (MCP) joint and less responsive to therapy. Insured patients may be less motivated than uninsured patients and less compliant with therapy. Joints with a greater degree of pre-treatment stiffness are felt to be less likely to respond to therapy and more likely to require surgical intervention.

Although clinicians currently use these variables to guide clinical reasoning and choice of intervention for each patient,<sup>23</sup> limited research data exist to justify the relative importance of these factors in influencing contracture resolution. Michlovitz et al.<sup>8</sup> conducted a systematic review of therapeutic interventions used for improving joint ROM, including splinting. They found evidence to support the positive effect of splinting in the management of joint contracture, yet stated that further research was needed on factors that may influence outcome, such as optimal dosage, wearing schedules, patient factors, and time since injury. We aimed to begin to address this gap in the literature by identifying clinical predictors of contracture resolution in joints of the hand, after an eight-week period of dynamic splinting.

## METHODS

### Participants

Participants were recruited from the Hand Clinics at EKCO Occupational Services in Brisbane, Queensland, Australia, from November 2004 to May 2008. Ethical approval was obtained from ethics committees at the University of Queensland and the recruitment site. All participants provided informed written voluntary consent.

Participants were included in the study if they met the following specific criteria: a history of traumatic injury to the upper limb resulting in joint contracture of the MCP or PIP joints of the hand, involved structures were adequately healed with the treating hand surgeon's approval to commence dynamic splinting, and passive ROM was less than or equal to 80% of the unaffected side to justify the use of splinting. Participants were excluded from the study if they had already used dynamic splinting for the current injury, abnormal tone/paralysis associated with central nervous system dysfunction was present, a diagnosis of complex regional pain syndrome type I or II (acute phase) had been made, or an inflammatory arthritic condition/progressive degenerative disease was present. Patients with an active infection in their finger or an artificial joint were also excluded.

## Materials

A standard silver finger goniometer (Surgical Synergies [importer], NSW, Australia) was used to take all AROM, PROM, and torque range of motion (TROM) measurements. A Haldex tension gauge (Jonard Industries Corp., Tuckahoe, NY, USA) was used to take TROM and torque angle curve (TAC) measurements, and to set splint tension.

## Demographic and Clinical Data

The predictor variables examined were clinical factors believed to potentially influence contracture resolution. Variables included age (years); three measures of pretreatment joint stiffness (TAC [degrees], modified Weeks Test [degrees], and end feel [springy or non-springy]); splint wear time (total end range time [TERT] measured in hours); time since injury (weeks); type of deficit (flexion, extension); diagnosis (intra-articular fracture, extra-articular fracture, soft tissue injury, volar plate); gender; joint type (MCP or PIP joint of fingers); mechanism of injury (e.g., crush, laceration, hyperextension, grinding); splint type (hand-made capener, dynamic flexion); and insurance status (workers' compensation, nonworkers' compensation). The continuous outcome variables were three measures of contracture resolution: change in PROM, change in AROM, and change in TROM, all measured in degrees.

## Procedures

### *Baseline Evaluation*

After recruitment, a verbal history was taken and a physical assessment was completed by the principal researcher, outlined as follows.

1. AROM, PROM, and TROM were recorded (lateral measurements) "cold" and "warm." That is, measurements were taken before and after preconditioning the joint using heat and 30 minutes of stretch.
  - a. AROM was recorded as the best possible movement obtainable by the patient's own efforts.
  - b. PROM was measured at the point before perception of pain where significant resistance to ongoing stretch was perceived. The examiner was guided by the patient's pain response and verbal feedback.
  - c. TROM was assessed using the Haldex tension gauge at 500 g in the movement of interest. The force was applied through the tip of the Haldex gauge at the volar distal interphalangeal (DIP) joint crease for extension deficits of the PIP joint, at the dorsal DIP crease for flexion deficits of the PIP joint, and at the dorsal PIP joint

crease for flexion deficits of the MCP joint. TROM was assessed in addition to PROM as it demonstrates high inter- and intrarater reliability in the hand.<sup>22,24,25</sup>

2. Joint stiffness was assessed manually using the end feel (springy or non-springy) technique. Joints that were rated as “springy” were those that when held at the end of available PROM demonstrated further increase in ROM with therapist application of increased manual stretch.<sup>11</sup> In contrast, joints with a “non-springy” end feel were those that demonstrated minimal improvement in PROM on therapist application of manual stretch.<sup>11</sup>
3. Joint stiffness was assessed using the TAC procedure.<sup>20,26</sup> The change in TROM between 800 and 200 g was used as the estimate of joint stiffness. Three TACs were taken before and three after preconditioning. **Figures 1 and 2** demonstrate the techniques used for taking TROM and TAC measurements.
4. A dynamic splint to suit the movement deficit was constructed. Consistent splint designs (i.e., dynamic flexion or hand-made dynamic capener splints) were used in this study (**Figures 3 and 4**). A mobilizing force of 200–250 g was set for each splint as recommended by Brand et al.<sup>27</sup>
  - a. Joint stiffness was then evaluated using a modification of the Weeks Test<sup>28</sup> involving 30 minutes of heat and stretch. This modified Weeks Test was also used as the preconditioning procedure. As all participants in this study were to commence a trial of dynamic splinting, the dynamic splint was used to stretch the stiff joint/s. After construction, the dynamic splint was applied for 30 minutes. A hot pack was used for the first 10 minutes in conjunction with the splint. The change in ROM over the



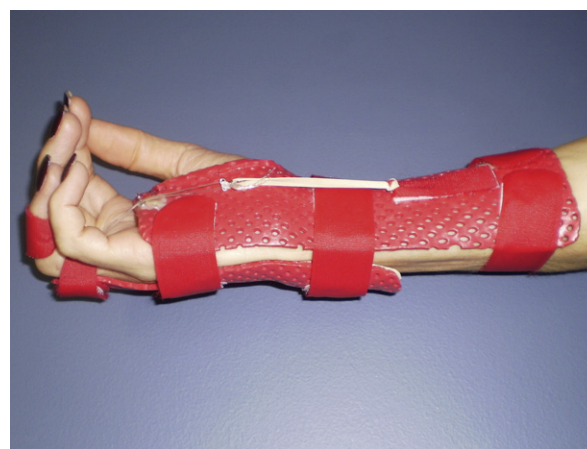
**FIGURE 1.** Method for taking torque range of motion and torque angle curve measurements for proximal phalangeal joint extension deficit. Proximal joints are stabilized in a neutral position while the force is applied through the tip of the Haldex gauge at the volar DIP joint crease.



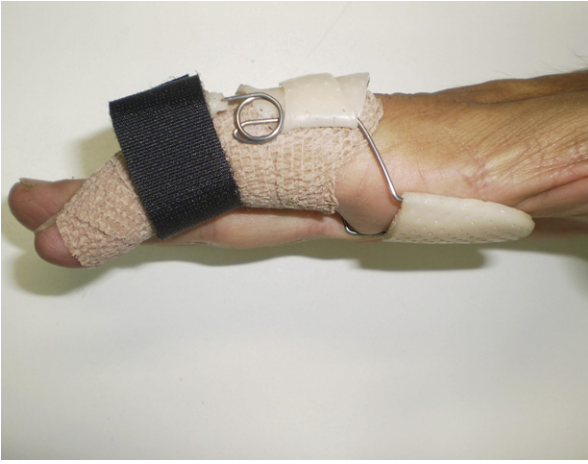
**FIGURE 2.** Method for taking torque range of motion and torque angle curve measurements for flexion deficit. The applicator of the Haldex gauge is applied to the dorsal crease of the PIP (for metacarpophalangeal joint deficit) or the DIP (proximal phalangeal joint deficit).

30-minute period provided the estimate of joint stiffness. A large change in ROM over the 30 minutes indicated a small degree of joint stiffness, whereas a small change in ROM indicated a high degree of joint stiffness. Unlike the original Weeks Test that utilized change in PROM, change in AROM was used in this study as its reliability in the hand has been demonstrated.<sup>29</sup>

- b. After preconditioning with the modified Weeks Test, AROM, PROM, TROM, end feel, and TAC were all reevaluated “warm.” Both warm and cold measures of joint stiffness and ROM were taken to determine the effect of preconditioning the joint.
- c. A subset of participants repeated the modified Weeks Test several days after baseline evaluation to examine the reliability and validity of this test. End feel and TAC assessments of joint



**FIGURE 3.** Dynamic flexion splint for the proximal phalangeal joint.



**FIGURE 4.** Dynamic capener splint for the proximal phalangeal joint.

stiffness were also reassessed at this time. This subset of participants commenced their home splinting program after completing the second modified Weeks Test.

Participants were educated about the purpose of their dynamic splint and their recommended wearing regimen (minimum 6–12 h/d as suggested by previous research).<sup>22</sup> Participants were provided with a splint diary and instructed to accurately record the number of hours/day they used their splint. This diary was checked regularly by the principal investigator at subsequent therapy sessions and used to evaluate daily end range time and TERT.

#### *Ongoing Intervention*

Participants attended therapy every one to two weeks. All splints were constructed and treatment was provided by the principal researcher to avoid proficiency bias. Proficiency bias is a form of intervention bias that occurs when the interventions or treatments are not applied equally to subjects. This may be due to differences in treatment approach among therapists and/or differences in resources or procedures used at different treatment sites.<sup>30,31</sup>

At these sessions, splint biomechanics and tension were checked and, if necessary, adjusted. AROM and TROM (at 500 g) were reevaluated to assess progress. All participants received a standard core treatment program, including dynamic splinting, active and assisted ROM, and edema management. Strengthening exercises were incorporated where appropriate according to the stage of tissue healing. Participants were monitored for adverse effects to splinting (e.g., edema, pain, circulatory problems). No adverse effects were found, and all participants tolerated the splint tension of 200–250 g.

To avoid measurement bias, an independent examination of participants' progress was conducted after eight weeks of splinting by a therapist not involved in providing treatment for participants.<sup>30</sup> The same assessment format was used as at the baseline evaluation.

#### **Data Analysis**

Test–retest reliability of the modified Weeks Test was analyzed using the intraclass correlation coefficient (ICC) (models 2 and 1). Convergent validity of the modified Weeks Test was assessed by determining its statistical associations with two other measures of joint stiffness, end feel (using one-way analysis of variance [ANOVA]), and TAC (using Pearson correlation). Dropouts were compared with those who stayed in the study using nonparametric analyses ( $\chi^2$ , Fisher's exact test, and Mann–Whitney U tests). For initial data screening, descriptive statistics (means, standard deviations [SDs], and percentages) were conducted on all predictor and outcome variables. To satisfy statistical assumptions, some predictor variables were recoded due to skewness or insufficient cell sizes. Mechanism of injury was recoded into complex forces (e.g., crush, grinding, twisting/torsional injury); simple forces/other (e.g., laceration, secondary contracture, infection); and hyperextension injuries (due to the large number of volar plate injuries). As the continuous variable time since injury was highly skewed and transformation would have made interpretation difficult, it was recoded into three categories: less than eight weeks, 8–12 weeks, and greater than 12 weeks. Five patients ( $n = 15$  joints) contributed more than one joint to the final sample of joints. To determine if this group of patients differed from the group with single joints on the three contracture resolution outcomes, Mann–Whitney U tests were conducted. Standard multiple linear regressions, using the generalized linear modeling procedure, were used to assess the influence of the predictor variables on the three outcome variables. Before the regression analyses, exploratory bivariate analyses (e.g., correlation,  $\chi^2$ , or one-way ANOVA) were conducted among all predictor variables to identify multicollinearity. Bivariate analyses between each predictor and outcome variable were then conducted. The set of predictor variables associated with each outcome at  $p \leq 0.1$  were identified. This conservative alpha level was chosen due to the exploratory nature of this research and the small sample size. For each regression model, the significant predictor variables identified from bivariate analyses were entered simultaneously, and then, backward elimination was used to identify the best model containing significant predictors (main effects and any two-way interactions)

at  $p \leq 0.05$ . Due to the large number of PIP joints in the sample (85.7%), regression analyses of a subset of just PIP joints were then conducted (both PIP flexion and extension contractures) to determine the variables associated with change in this subset. Data analysis was conducted using SPSS (SPSS Inc, Chicago, IL, USA), version 17.

## RESULTS

### Demographic and Clinical Data

During the data collection period, 65 potential participants were identified. Of these, 13 were excluded as they did not meet the selection criteria, leaving 52 eligible participants who were recruited to the study. Six of the 52 participants (seven joints) dropped out leaving a final sample of 46 participants (56 joints). Clinical characteristics of the final sample and dropouts are presented in Table 1. Analysis of differences between the final study sample and dropouts was not significant at  $p \leq 0.05$ . However, due to the small number of dropouts in the study, interpretation of this finding requires some caution.

The average improvement in the final full sample of joints (MCP and PIP,  $n = 56$ ) was as follows: PROM,  $21.8^\circ$  (SD,  $8.3^\circ$ ); AROM,  $20.0^\circ$  (SD,  $10.4^\circ$ ); and TROM,  $13.0^\circ$  (SD,  $8.2^\circ$ ). The average improvement in the PIP joint subset ( $n = 48$ ) was as follows: PROM,  $21.7^\circ$  (SD,  $8.5^\circ$ ); AROM,  $19.8^\circ$  (SD,  $10.6^\circ$ ); and TROM,  $12.7^\circ$  (SD,  $7.9^\circ$ ). The average daily TERT for the final full sample ( $n = 56$ ) was 7.96 h/d.

### Preliminary Exploratory Analysis

Analysis of the contracture resolution outcomes by whether the patients contributed one or multiple joints to the sample showed no differences between the groups for AROM ( $p = 0.48$ ), PROM ( $p = 0.86$ ), and TROM ( $p = 0.37$ ); therefore, all joints were retained for the final analysis.

Preliminary bivariate analysis of the relationships among the predictor variables revealed significant associations in some cases, suggesting that these variables were related in some way and, to some extent, testing the same underlying concept. Significant associations were found between time since injury and diagnosis ( $p \leq 0.05$ ); diagnosis and deficit ( $p \leq 0.05$ ); diagnosis and splint type ( $p \leq 0.05$ ); and deficit and splint type ( $p \leq 0.001$ ). As deficit and splint type were highly associated, only deficit was used in the final multivariate analyses. Bivariate analysis also identified which of the predictor variables were tentatively associated with the outcome variables (change in AROM, PROM, and TROM) at  $p \leq 0.1$  (Table 2). These predictor

TABLE 1. Descriptive Characters of Final Sample and Dropouts

Predictors	Final Sample (N = 56)	Dropouts (N = 7)
Age mean in years (SD, range)	44.2 (15.0, 15–76)	34.9 (13.7, 19–56)
Deficit (%)		
Flexion loss	66.1	57.1
Extension loss	33.9	42.9
Diagnosis (%)		
Intra-articular fracture	23.8	28.6
Extra-articular fracture	14.3	14.3
Soft tissue	39.7	57.1
Volar plate injury	22.2	0
Gender (%)		
Male	57.1	71.4
Female	42.9	28.6
Joint type (%)		
Metacarpophalangeal finger	10.7	14.3
Proximal phalangeal finger	85.7	57.1
Interphalangeal thumb	3.6	14.3
Metacarpophalangeal thumb	0	14.3
Mechanism of injury (%)		
Hyperextension	39.3	0
Crush	25.0	42.9
Secondary contracture	8.9	0
Twisting	7.1	0
Hyperflexion	7.1	0
Pilon injury	7.1	0
Grinding	3.6	0
Laceration	0	42.9
Infection	0	14.3
Splint type (%)		
Capener	33.9	42.9
Dynamic flexion	66.1	57.1
End feel (%)		
Springy	53.6	14.3
Non-springy	46.4	85.7
Mean torque angle curve in degrees (SD, range)	15.1 (6.5, 2.3–37)	13.6 (7.2, 6–24)
Mean Weeks Test in degrees (SD, range)	12.2 (6.2, 3–40)	10.9 (5.4, 2–16)
Mean time since injury in weeks (SD, range)	14.0 (9.3, 5–33)	11.2 (4.7, 5–18)
Workcover status		
Non workcover	73.2	100
Workcover	26.8	0
Digit		
Thumb	3.6	28.6
Index	19.6	28.6
Middle	23.2	14.3
Ring	23.2	0
Small	30.4	28.6
Mean total end range time in hours over 8 wk (SD, range)	446.0 (168.9, 203.5–1008.0)	

SD = standard deviation.

variables were then subsequently included in the regression models.

## Reliability and Validity of the Modified Weeks Test

Twenty-seven participants returned to therapy several days after their initial assessment for the modified Weeks Test to be repeated. Test–retest reliability was 0.78 (ICC: 2, 1) (95% confidence interval, 0.51–0.89), indicating good reliability. Association between the modified Weeks Test and the TAC assessment of joint stiffness ( $n = 16$ ) was poor ( $r = 0.45$ ,  $p = 0.08$ ). Likewise, the relationship between end feel and the modified Weeks Test ( $n = 16$ ) was also poor ( $F_{(1,14)} = 1.09$ ;  $p = 0.314$ ).

## Analysis of Change in Contracture Resolution: Full Sample ( $n = 56$ )

### Change in AROM

Four predictor variables identified from bivariate analyses were entered into the regression model: time since injury, diagnosis, joint stiffness (modified Weeks Test), and TERT. After backward elimination, the final best model for change in AROM was significant ( $F_{(4,51)} = 14.91$ ;  $p \leq 0.001$ ) with pretreatment stiffness (measured using the modified Weeks Test) and diagnosis the significant predictors, together explaining 56% of the improvement observed. Table 3 shows the regression estimates and marginal means. For every change of  $1^\circ$  on the modified Weeks Test, there was a change of  $1.09^\circ$  (standard error [SE],  $0.2^\circ$ ) in AROM. Improvement in AROM was greatest for those with an extra-articular fracture or volar plate injury. These two groups had significantly greater AROM compared with intra-articular fractures or soft tissue injuries on post hoc comparisons (i.e., extra-articular versus intra-articular fracture [ $p = 0.005$ ]; extra-articular fracture versus soft tissue [ $p = 0.001$ ]; volar plate versus intra-articular fracture [ $p = 0.029$ ]; and volar plate versus soft tissue [ $p = 0.010$ ]).

### Change in PROM

Three predictor variables identified from bivariate analyses were entered into the regression model: diagnosis, joint stiffness (modified Weeks Test), and deficit. After backward elimination, the final best model for change in PROM was significant ( $F_{(1,51)} = 4.32$ ;  $p \leq 0.05$ ), with type of deficit explaining 8% of the improvement in PROM (Table 4).

### Change in TROM

None of the predictor variables were associated with change in TROM ( $F_{(1,46)} = 3.56$ ;  $p = 0.07$ ).

TABLE 2. Bivariate Associations between Predictor and Outcome Variables: Full-Sample MCP and PIP Joints ( $n = 56$ ) and PIP-only Subset ( $n = 48$ )

Predictor Variable	Change in AROM		Change in PROM		Change in TROM	
	Full Sample ( $n = 56$ )	PIP Sample ( $n = 48$ )	Full Sample ( $n = 56$ )	PIP Sample ( $n = 48$ )	Full Sample ( $n = 56$ )	PIP Sample ( $n = 48$ )
Time since injury	$F_{(2,52)} = 2.73$ ; $p = 0.08$	$F_{(2,44)} = 3.55$ ; $p = 0.04$	$F_{(2,51)} = 0.54$ ; $p = 0.58$	$F_{(2,43)} = 0.85$ ; $p = 0.44$	$F_{(2,51)} = 1.38$ ; $p = 0.26$	$F_{(2,40)} = 2.13$ ; $p = 0.14$
Diagnosis	$F_{(3,51)} = 2.14$ ; $p = 0.10$	$F_{(3,43)} = 1.48$ ; $p = 0.23$	$F_{(3,50)} = 2.14$ ; $p = 0.10$	$F_{(2,42)} = 1.92$ ; $p = 0.14$	$F_{(3,47)} = 0.58$ ; $p = 0.63$	$F_{(3,39)} = 0.72$ ; $p = 0.55$
Weeks Test	$r = 0.63$ ; $p < 0.001$	$r = 0.64$ ; $p < 0.001$	$r = 0.26$ ; $p = 0.06$	$r = 0.26$ ; $p = 0.09$	$r = 0.27$ ; $p = 0.07$	$r = 0.27$ ; $p = 0.09$
TERT	$r = -0.26$ ; $p = 0.05$	$r = -0.29$ ; $p = 0.05$	$r = -0.18$ ; $p = 0.19$	$r = -0.22$ ; $p = 0.15$	$r = -0.17$ ; $p = 0.25$	$r = -0.17$ ; $p = 0.29$
Deficit	$F_{(1,53)} = 1.13$ ; $p = 0.29$	$F_{(1,45)} = 0.99$ ; $p = 0.32$	$F_{(1,52)} = 5.22$ ; $p = 0.03$	$F_{(1,44)} = 5.21$ ; $p = 0.03$	$F_{(1,49)} = 1.65$ ; $p = 0.21$	$F_{(1,41)} = 1.43$ ; $p = 0.24$

Associations significant at  $p \leq 0.10$  are emboldened.

MCP = metacarpophalangeal; PIP = proximal phalangeal; AROM = active range of motion; PROM = passive range of motion; TROM = torque range of motion; TERT = total end range time.  $p > 0.1$  means not significant.

**TABLE 3. Best Multiple Linear Regression Models for Analysis of Change in AROM (in Degrees) in the Full Sample (MCP and PIP Joints) and PIP Subset at  $p \leq 0.05$ : Regression Estimates ( $\beta$  [SE]) for Continuous Predictors and Marginal Means (95% CIs) for Categorical Predictors**

<i>Significant Predictors</i>	<i>Full Sample*</i>	<i>p Value</i>	<i>PIP Subset†</i>	<i>p Value</i>
Diagnosis, mean change in AROM (95% CIs)		0.002	NA	
Soft tissue	16.8 (13.6–20.2)			
Intra-articular fractures	17.6 (13.6–21.6)			
Extra-articular fractures	27.2 (22.1–32.4)			
Volar plate	24.2 (19.8–28.6)			
Weeks Test, $\beta$ (SE)	1.09 (0.2)	<0.000	1.02 (0.2)	<0.000
Time since injury (weeks), mean change in AROM (95% CIs)	B			0.031
<8			23.7 (19.9–27.6)	
8–12			20.1 (15.3–24.9)	
>12			16.1 (12.0–20.2)	

AROM = active range of motion; MCP = metacarpophalangeal; PIP = proximal phalangeal; SE = standard error; CI = confidence interval; B = removed during backward elimination; NA = not included in model.

\* $R^2 = 0.56$ .

† $R^2 = 0.51$ .

### Multivariate Analysis of Change in Contracture Resolution in the Proximal Phalangeal Joint Subset ( $n = 48$ )

#### *Change in AROM*

Three predictor variables were entered into the regression model: time since injury, modified Weeks Test, and TERT. After backward elimination, the final best model for change in AROM was significant ( $F_{(3,39)} = 13.72$ ;  $p \leq 0.001$ ) with the modified Weeks Test and time since injury, accounting for 51% of the improvement observed. Table 3 shows the regression estimates. For every change of  $1^\circ$  on the modified Weeks Test, there was a change of  $1.02^\circ$  (SE,  $0.2^\circ$ ) in AROM. The longer the time since injury, the fewer were the gains made in AROM, and post hoc comparison showed significant difference between “less than eight weeks” and “greater than 12 weeks,” at  $p \leq 0.01$ .

#### *Change in PROM*

Two predictor variables were entered into the regression model: the modified Weeks Test and deficit. After backward elimination, the final best model for change in PROM was significant ( $F_{(1,41)} = 4.14$ ;

$p \leq 0.05$ ). Change in PROM was greater for those with loss of flexion than those with loss of extension (Table 4), accounting for 9% of the improvement observed.

#### *Change in TROM*

None of the predictor variables were associated with change in TROM ( $F_{(1,38)} = 2.02$ ;  $p = 0.09$ ).

## DISCUSSION

Our aim was to identify the clinical variables that influence outcome with dynamic splinting, to help guide clinical decision making in the management of the stiff hand after trauma. Splinting outcome was evaluated by an independent examiner. Contracture resolution was measured by means of change in PROM, AROM, and TROM. Preliminary bivariate analyses were conducted to look at the relationship between predictor variables as well as the relationship between each of the predictor variables and each of the outcome measures. These preliminary analyses allowed us to identify which of the clinical variables appeared to be related to the outcome measures. These clinical variables were then included in the formal regression models. The advantage of using a

**TABLE 4. Best Multiple Linear Regression Models for Analysis of Change in PROM (in Degrees) in the Full Sample (MCP and PIP Joints) and PIP Subset at  $p \leq 0.05$ : Regression Estimates ( $\beta$  [SE]) for Continuous Predictors and Marginal Means (95% CIs) for Categorical Predictors**

<i>Significant Predictors</i>	<i>Full Sample*</i>	<i>p Value</i>	<i>PIP Subset†</i>	<i>p Value</i>
Deficit, mean (95% CIs)		0.043		0.048
Loss of flexion	23.3 (20.4–26.1)		23.6 (20.2–26.9)	
Loss of extension	18.3 (14.3–22.1)		18.3 (14.3–22.3)	

\* $R^2 = 0.08$ .

† $R^2 = 0.09$ .

multivariate procedure, such as regression, over bivariate analyses, such as simple correlation, is that it considers all variables included in the model simultaneously. As such, it can allow for interactions between predictor variables that may occur in the clinical setting and, as such, the findings may be more widely applied to the general community. Regression models were developed for each outcome measure (AROM, PROM, and TROM) and for both the full sample of MCP and PIP joints as well as the PIP subset.

The best predictors of improvement in AROM in the full sample (MCP and PIP,  $n = 56$ ) of joints were diagnosis and pretreatment stiffness, as measured using the modified Weeks Test. The modified Weeks Test and diagnosis collectively explained about half (56%) of the change in AROM. Most of the gains in AROM were seen in the extra-articular fracture group ( $27.2^\circ$ ) followed by volar plate injury ( $24.2^\circ$ ), intra-articular fractures ( $17.6^\circ$ ), and lastly, soft tissue injuries ( $16.8^\circ$ ). The finding that extra-articular fractures made greater progress than intra-articular fractures seemed logical given that the articular surface of the joint was not involved in the injury. The poor progress experienced by those with soft tissue injuries was unexpected. However, on further examination of this subset, it was found that the average time since injury (18.7 weeks) was substantially longer in the soft tissue group compared with intra-articular fractures (8.7 weeks), extra-articular fractures (12 weeks), and volar plate injuries (11.2 weeks). This was due to late referral of soft tissue injuries to therapy. Hence, it is likely that the tissue healing process was more advanced and changes within these joints had become more fixed and more resistant to splinting treatment. This finding suggests that it is important not to underestimate the significance of trauma involving soft tissues as, if neglected early on, much poorer outcome may result. Timely referral to hand therapy is desirable.

The best predictors of change in AROM in the PIP joint subset were time since injury and the modified Weeks Test. These two variables explained about half (51%) of the change in AROM. The shorter the time since injury (e.g.,  $<8$  weeks), the greater the gains made in AROM. This observation is similar to that of Foucher et al.,<sup>21</sup> who found that if time since injury exceeded two months, fewer gains in ROM were made.

Type of deficit predicted change in PROM in both the full and PIP joint samples: improvement in PROM was greater for participants with flexion loss. However, in both of these samples, deficit explained less than 10% of the change in PROM (8% full sample and 9% PIP subset). This limits our capacity to draw firm conclusions from this finding. However, it does support the clinical experience that, in the PIP joint, it is harder to regain extension than flexion.

None of the variables were found to predict change in TROM in either the full sample or PIP subset, which was surprising given that this is essentially a more reliable method of assessing PROM. In our sample, TROM was generally found to be less than PROM assessed manually. This would indicate that the 500-g force applied using the TROM method was less than that applied with manual assessment of PROM. It is possible that the use of a higher force in the TROM technique may have produced different results and may have reflected more accurately true PROM. However, it has been our experience with the TROM technique that the use of force greater than 500 g is not always well tolerated. Many of the joints assessed were PIP joints, and the little finger was most commonly affected. The use of a metal silver goniometer to record ROM contributes to this problem. When higher force levels were applied (e.g., up to 800 g with the TAC technique), patients would occasionally report some discomfort over the dorsum of the joint as a result of pressure experienced through the metal goniometer. Hence, we chose the conservative force of 500 g. Future studies should consider experimenting with alternative goniometer styles and higher levels of force to measure TROM.

The modified Weeks Test assessment of joint stiffness used in this study was an important predictor of response to dynamic splinting. For every degree change in ROM using the modified Weeks Test, AROM improved by  $1.09^\circ$  in the full sample of joints and  $1.02^\circ$  in the PIP joint subset. Test–retest reliability of the modified Weeks Test was good (ICC [2, 1] = 0.78). However, we were not able to demonstrate convergent validity using comparison with TAC and end feel. Convergent validity refers to the concept that two measures believed to test the same underlying phenomenon (e.g., joint stiffness) will correlate highly.<sup>32</sup> It is possible that our lack of significant findings may be due to the small sample size. Alternatively, it may be that these measures do, in fact, test different aspects of joint stiffness.

Connective tissue is “viscoelastic” in nature.<sup>15,20</sup> Collagen and elastin fibers within connective tissue comprise the elastic factors, whereas the ground substance in the extracellular matrix and edema constitute the viscous component. Both viscous and elastic elements are involved in the response of connective tissue to applied stress. The modified Weeks Test provides a good assessment of the viscous component of joint stiffness by studying the compliance of tissues over time with a constant force.<sup>20</sup> In contrast, the TAC and end feel techniques appear to assess a combination of both elastic and viscous factors contributing to stiffness. With the modified Weeks Test, the joint is held on stretch at a constant level of force for a prolonged period, and fluid is slowly pushed away, allowing collagen fibrils room to slide past each other, known as “stress relaxation.”<sup>20</sup> Joints with a greater



change in ROM over the 30-minute test may have a greater percentage of viscous stiffness, which in turn, may make these joints more likely to respond to therapy. In contrast, joints with a small change in ROM over 30 minutes may be comprised of a higher percentage of elastic stiffness associated with changes that have occurred within the collagen matrix, such as crosslink formation and collagen shortening. If these changes are in place for a lengthy period of time, the ability of the collagen to remodel to allow functional ROM may be limited.

Our findings support recommendations by Flowers<sup>23</sup> that the modified Weeks Test has the potential to be used to plan treatment options for our patients. For example, if change in AROM over 30-minute heat and stretch is negligible, the expected improvement with conservative interventions, such as splinting, would also be minimal. Hence, surgical intervention may be needed. Further research is needed to examine the accuracy with which the modified Weeks Test may predict contracture resolution.

The modified Weeks Test was the only pretreatment measure of joint stiffness related to outcome with splinting for contracture resolution. The TAC technique for assessing joint stiffness is relatively difficult to master and, given its lack of significance as a predictor of outcome in this study, its use may not be justified in everyday clinical practice. Likewise, assessment of joint stiffness using the end feel (springy or non-springy) technique was not a significant predictor in this study. Additionally, previous research has questioned the reliability of the end feel technique for evaluating joint stiffness in the hand,<sup>26</sup> and hence, we recommend that it should no longer be used to plan treatment options.

Splint wear time (TERT) was not found to be associated with contracture resolution in the multivariate analyses although weakly correlated with change in AROM in the bivariate analyses (Table 2). TERT was not correlated with either change in PROM or TROM in the bivariate analyses. The importance of TERT in overcoming joint stiffness has been well established in previous studies, and we do not suggest that our findings indicate otherwise.<sup>22,25,33</sup> Our conflicting results are most likely due to our small sample size and insufficient power to detect a significant relationship using multivariate regression analysis. It is also possible that an interaction effect between TERT and other variables included in the analysis has masked the true relationship between TERT and contracture resolution. Additionally, the lack of variability in daily TERT within our sample may have contributed to our negative finding. All participants in this study wore their splints for a lengthy period of time each day (average, 7.96 hours), well over the 6 h/d recommended by previous research.<sup>22</sup>

## Study Limitations

The relatively small sample size (56 joints) is a limitation of this study as it reduces the power to detect significant relationships between variables (type II error)<sup>32</sup> and may partly explain the observation that none of the predictor variables influenced change in TROM in either the full or PIP joint samples. Despite this, the sample size represented most of the population of stiff joints presenting to the hand clinic during the period of data collection with only 13 of 65 possible participants excluded.

The generalizability of the study findings is limited by the nature of participant selection.<sup>32</sup> All participants were volunteers and may have been more motivated than the general population of hand trauma patients. Nonparametric statistical analysis found no differences between the final sample and the dropout group (Table 1); however, the number of dropouts was low. The final study sample did appear representative of the wider population of hand-injured patients undergoing splinting for joint contracture (i.e., mostly men, predominantly PIP joint, little finger most commonly affected, hyperextension or crush injury, average time since injury of 14 weeks, average daily TERT of eight hours).<sup>22,25,26,33,34</sup> Although all outcome measures were completed by an independent assessor to reduce the risk of measurement bias, all treatment was provided by the same researcher. This was done to ensure a consistent approach to splint construction, splint monitoring, and treatment implementation, and to avoid bias that may result from differing therapist treatment styles (intervention bias).<sup>30,31</sup> This helps to improve the internal validity of the study findings but may limit external validity (applicability across multiple clinical settings).<sup>32</sup>

Another study limitation relates to the unexpected finding that the predictors were found to be related to improvement in AROM rather than PROM. PROM is usually considered to be the gold standard in monitoring joint stiffness rather than AROM. This may again be a product of the small sample size and inability to detect certain relationships as a result of reduced statistical power. Despite this, however, it could also be argued that, at the end of the day, the overall goal of dynamic splinting is to improve hand function, which is, perhaps, more accurately reflected in the motion that a patient can achieve independently using their own muscles.

## Clinical Implications and Recommendations

From this exploratory research, it is possible to make some tentative recommendations.

1. Although pretreatment joint stiffness assessed using the modified Weeks Test was a consistent

predictor of outcome with dynamic splinting in this study, further examination of the accuracy with which this test predicts change in ROM is required.

2. Early intervention with splinting treatment is advisable to improve clinical outcome. Poorer progress may be expected if splinting is commenced after two to three months postinjury.
3. Faster recovery of ROM may be expected when splinting for flexion rather than extension deficits.
4. Many of the variables we consider to be predictive of outcome, such as age, gender, insurance status, and mechanism of injury, may, in fact, not be strongly predictive of outcome with dynamic splinting for contracture resolution. Further research is needed with a larger sample size to exclude the possibility of a type II error.

## CONCLUSIONS

We found that the most important predictors of outcome with eight weeks of dynamic splinting in this study were pretreatment joint stiffness, as measured using the modified Weeks Test, time since injury, diagnosis, and deficit (flexion or extension). Early intervention with dynamic splinting is important as the best results are seen if splinting is commenced in the first two to three months postinjury. Along with time since injury, the modified Weeks Test assessment of joint stiffness may potentially be used by clinicians to tentatively gauge the expected outcome with splinting treatment. Further research is required.

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- #1. Key factors found to predict outcome with dynamic splinting in this study included
- time since injury
  - diagnosis
  - joint stiffness
  - all of the above
- # 2. The main purpose of this study was to
- conduct a randomized controlled trial of the benefits of splinting
  - evaluate the response to splinting treatment over time
  - investigate the relationship between key clinical variables and splinting outcome in a prospective clinical trial
  - conduct a retrospective case review of splint use to manage joint stiffness
- #3. The best measure of joint stiffness for predicting response to splinting treatment in this study was
- the Modified Weeks Test
  - the TAC technique
  - the end feel technique
  - all of the above
- #4. A limitation of this study was
- large sample size
  - small sample size
  - use of a prospective rather than retrospective design
  - b and c
- #5. Results from this study suggest that better progress with dynamic splinting will be observed in
- extension deficits that are greater than 12 weeks post injury
  - flexion deficits less than 8 to 12 weeks post injury
  - soft tissue injuries
  - intra-articular fractures

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