Optimal Daily Total End Range Time for Contracture:

Resolution in Hand Splinting

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ABSTRACT: Reduced passive range of motion (PROM) of the joints of the hand is a common sequela of traumatic upper limb injury. Although mobilizing splinting is a common modality used by hand therapists to improve PROM, limited empirical evidence is available to guide therapist prescription. This study investigated the importance of the timing of splint application per 24-hour period, *daily total end range time* (TERT), via a prospective sequential clinical trial. A total of 43 subjects with joint contractures of the hand after traumatic upper limb injury were randomly allocated to one of two splint programs. Subjects in group A used their splint for less than 6 hours per day, and subjects in group B used their splint for 6 to 12 hours per day. Daily TERT was recorded by subjects in a splint diary. Passive torque range of motion (TROM) was used to measure the extent of contracture resolution over four weeks of splinting. High intrarater, interrater, and test-retest reliability of the TROM technique was established for this sample (intraclass correlation coefficients 0.993 to 0.998). Sequential analysis showed a statistically significant preference for group B, daily TERT of 6 to 12 hours per day ($p < 0.05$). Pretreatment joint stiffness ($p = 0.162$) and joint type ($p = 0.463$) did not influence final TROM significantly. These findings help to provide some controlled data from which therapists may base future prescription (dose) of daily TERT.

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Hand therapists frequently are faced with the problem of restoring passive range of motion (PROM) to the joints of the hand following traumatic injury to the upper limb. Hand splinting is accepted by many therapists as the modality of choice for improving PROM by the application of low load prolonged stress.[1–5] Mobilizing splints, in particular, are used to improve PROM in the presence of joint stiffness and may include dynamic splints, static progressive splints, and serial static splints.[2]

Despite the frequent use of mobilizing splints to improve PROM, little empirical evidence exists to guide the therapist in splint prescription and choice of wearing regimen. McClure et al.[6] suggested an algorithm to guide splinting choices, and Flowers[7] proposed a hierarchy of decision making for splinting the stiff joint. However, most authors make recommendations about the timing of splint application solely on the basis of clinical experience. Several factors are known to limit the amount and duration of force application, including the tolerance of skin and local circulation to pressure, the stage of tissue repair, and individual pain tolerance. The optimal quantity or timing of the torque required for optimal resolution of joint contracture remains unknown.[2,3,6–11]

The lack of quantitative evidence in the literature is reflected in clinical practice. Considerable variation in choice of daily splint wearing regimen was found among Australian hand therapists in response to a survey conducted in 1999, with no consensus on the optimal program.[12] Without further research exploring suitable parameters for corrective splinting and in particular optimal timing of torque application, much is left to subjective clinical judgment. Errors in

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clinical reasoning may become more common, and the risk of following routine procedures in an inappropriate situation is increased.[13,14]

OPTIMAL END RANGE TIME (DAILY TOTAL END RANGE TIME)

Total end range time (TERT) is the term developed by Flowers and LaStayo[15] to describe the amount of time that a joint is held at the end of its range. Flowers and LaStayo[15] studied TERT in relation to resolution of PIP flexion contractures. Subjects who experienced a TERT of six days showed twice the improvement in PROM than those in the 3-day group. It was concluded that the increase of PROM of a stiff joint was directly proportional to TERT.

TERT may be used to refer to the total number of hours per day, week, or month of splinting time. It quantifies the dose of treatment received by the patient, within a given time frame.[2] Prosser[16] referred to two components of TERT—splint wear time and splint duration—in an attempt to distinguish daily splinting time (e.g., six hours a day) from cumulative splint time (e.g., six hours a day over three months). The focus of the current study is to examine daily splint use or daily TERT, rather than cumulative splint duration. Specifically, *daily TERT* refers to the number of hours per day that a joint is held at the end of available PROM, via a mobilizing splint.

Limited research is available in relation to daily wearing regimens and mobilizing splinting. Kolumban[17] conducted an early clinical trial in the management of proximal interphalangeal (PIP) flexion contractures and examined the question of optimal daily TERT as part of his analysis. No significant difference was found between a daily TERT of 11 or 22 hours.[17] Luster et al.[18] studied flexion assist splinting to address extension contractures of the metacarpophalangeal (MCP) joints after burns. The degree of pretreatment joint stiffness was found to influence the treatment outcome but not daily TERT. Specifically, subjects with greater pretreatment joint stiffness did not experience the same amount of contracture resolution as subjects with less stiff joints. This finding in relation to joint stiffness supports recommendations in hand therapy literature that relate the success of splinting in contracture resolution to pretreatment stiffness.[4] Specifically, it traditionally has been concluded that joints with a "springy" end feel (less stiff) respond more positively to splinting than joints with a "hard/nonspringy" end feel (more stiff).[1,4] This conclusion is not fully supported, however, by the findings of Prosser[16] in her study of splinting in the management of flexion contractures of the PIP joint. Contrary to Luster et al.,[18] Prosser[16] found that pretreatment joint stiffness did not clearly influence resolution of contracture. Correlation analysis showed a significant relationship between pre treatment joint stiffness and final extension deficit. However, the use of a multiple regression analysis of variance procedure was unable to further substantiate this relationship.[16] Prosser[16] hypothesized that these conflicting results may have been due to small sample size or to other unidentifiable factors, such as differences in tissue pathology. Prosser[16] concluded that splint duration (cumulative splint time or TERT) was the most important factor influencing resolution of joint contracture and highlighted the need to identify the most clinically effective splint wearing time (daily TERT) and splint duration (cumulative TERT).[16] The primary aim of this study was to explore the relationship between daily TERT and the efficacy of contracture resolution. The impact of the degree of pretreatment joint stiffness also was examined.

MEASUREMENT OF JOINT CONTRACTURE

Historically, PROM has been used by therapists as a means of assessing joint contracture and the need for corrective splinting. The reliability of PROM has been shown to be poor, however, because of error associated with the lack of application of a standard torque and inconsistent positioning.[19,20] Passive torque range of motion (TROM) was introduced into the hand clinic by Brand and Hollister[10] as an alternative to PROM. The TROM technique used in this study was modified from guidelines recommended by Brand and Hollister[10] and applied to a variety of joints, including interphalangeal (IP) and MCP joints of fingers and thumbs. Flexion and extension contractures were studied. These factors are unique to this study. Previous research with the TROM technique has concentrated on one specific joint and one movement at a time. It was essential to investigate intrarater, interrater, and test-retest reliability of the TROM technique for the specific study sample.

RESEARCH HYPOTHESES

This study explored the following research hypotheses:

- The TROM technique will be found to be a reliable measure of the extent of contracture resolution for IP and MCP joints of fingers and thumbs in the study sample.
- There will be a difference in the extent of resolution of joint contracture (measured using TROM) between subjects in group A (daily TERT $<$6 hours per day) and subjects in group B (Daily TERT of 6 to 12 hours per day), after four weeks of mobilizing splinting.

- Pretreatment degree of joint stiffness will influence the extent of contracture resolution after four weeks of mobilizing splinting.

METHOD

Study Design

A prospective randomized sequential clinical trial (SCT) was used. This design reduces the number of subjects required for a clinical trial without compromising statistical power.[21,22] Subjects were paired chronologically as they entered the study and compared in relation to their ability to achieve a clinically significant result. Preferences for group A or group B were plotted on a predetermined sequential chart according to the specifications of Armitage.[22] The trial was stopped when the significance boundary was reached.

Participants

Forty-three consecutive adult volunteers presenting to the hand therapy unit at a major public hospital in Brisbane, Australia, in 2000 were recruited into the study. All subjects met specific selection criteria. There were 32 subjects who completed the four-week splint program (22 men and 10 women). One joint was studied per subject. All subjects had a history of traumatic hand injury followed by a reduction in PROM. Duration of presence of contracture ranged from 4 to 30 weeks. Subjects with central nervous system dysfunction, complex regional pain syndrome, inflammatory arthritic conditions, or joint replacements were excluded from the study. All subjects provided written informed consent before random allocation to splint group.

Materials

A standard silver finger goniometer (Smith & Nephew Inc., Germantown, WI) and a Haldex tension gauge (JID tools Jonard, Tuckahoe, NJ) were used to take all TROM measurements.

Procedures

Subjects were randomly assigned to one of the two splint groups using a random permuted block design.[23] This is a method of counterbalancing recruitment that ensures equal numbers of subjects are randomly allocated to each group. This is particularly important in a SCT, in which theoretically the trial could be stopped at any point if it is clear that a significant/nonsignificant boundary has been reached. Subjects remained blinded and were not informed of the splint parameters for the alternative group. Subjects in group A were instructed to wear their splint for less than 6 hours per 24-hour period. Subjects in group B were instructed to wear their splint greater than 6 but less than 12 hours per 24-hour period. Subjects were advised that splint use could be intermittent or continuous, as individual variation in circulation and pain tolerance was acknowledged. Baseline data were collected on the following variables: age, sex, time since injury, diagnosis, pretreatment joint stiffness, medical and surgical history, dominance, previous therapy received, and worker's compensation status.

Torque Range of Motion Technique

TROM was assessed weekly in therapy during the four-week splint program. Pretreatment (presplint) TROM was compared with posttreatment (after four weeks of splinting) TROM to evaluate the extent of contracture resolution. TROM was assessed using a constant force (500 g) applied with the Haldex gauge for 10 seconds. A small rubber stopper was secured to the applicator on the Haldex gauge to increase patient comfort during force application. A constant moment arm was obtained by applying the Haldex gauge perpendicular to the hypothetical axis of the joint, at specified anatomic landmarks (e.g., distal interphalangeal [DIP] or PIP creases). Standard positions were used for all measurements. Positions and procedures were modeled on the guidelines recommended by earlier authors (Figure 1).[10,15,16,24–26]

Baseline (presplint) assessment of TROM was completed without preconditioning the joint. Subsequent weekly TROM measurements were performed following a specific preconditioning sequence including 10 minutes of splint use followed directly by 10 minutes of splint use combined with heat, at the start of the therapy session. TROM was assessed directly following removal of heat and splint. The aim of preconditioning was to counteract the effect of factors that otherwise may influence TROM readings, such as diurnal variation, temperature, and prior activity level.

Measurement of Joint Stiffness

Torque angle curves (TAC) were used to evaluate the degree of pretreatment joint stiffness. TROM measurements were taken at 100 g, 200 g, 300 g, 400 g, 500 g, 600 g, and 800 g. A maximum level of 800 g was used on the basis of the work of earlier authors.[15,24,26] The subsequent TAC was plotted on a graph of range of motion and torque according to the guidelines outlined by Brand and Hollister.[10] A long gradual TAC indicated mild stiffness with a greater viscous component. A steep short TAC indicated a greater degree of stiffness with a larger elastic component (Figure 2). An estimate of the slope of the TAC (and

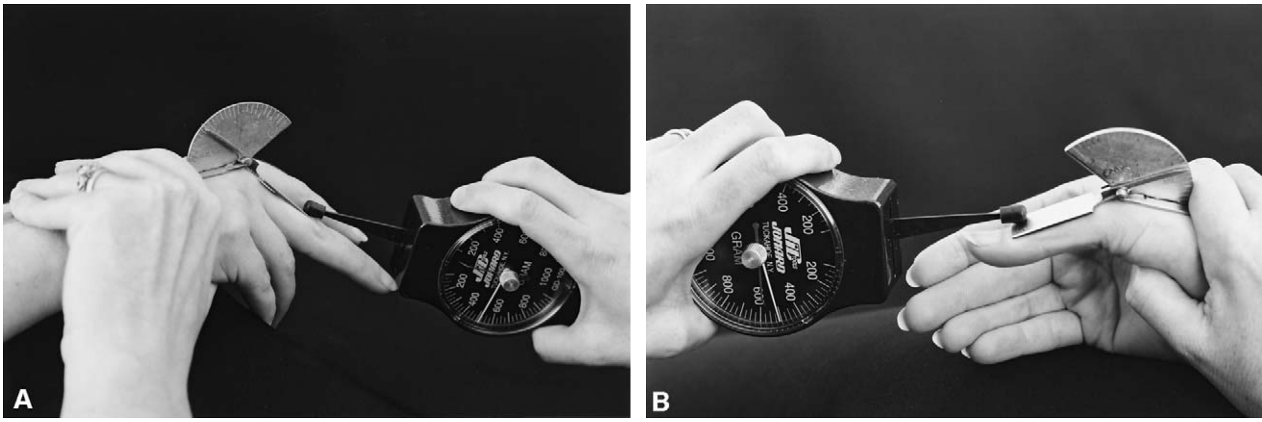


FIGURE 1. *Assessing TROM for flexion of the MCP joint of the index finger (**A**) and MCP joint of the thumb (**B**).*

the degree of stiffness) can be made by substracting TROM at one point from TROM at another point on the curve.[10,27,28] For the purposes of this study, degree of stiffness was estimated by substracting TROM at 200 g from TROM at 800 g. The higher the resultant figure in degrees, the lower the pretreatment degree of joint stiffness.

Intervention

All subjects attended therapy once a week. After heat and assessment of TROM, treatment included splint review and passive and active mobilization. All subjects received a home program including splinting and active range of motion (tendon gliding exercises). Use of the injured hand in functional activities also was encouraged. Dynamic flexion assist splints and a modification of the belly gutter splint described by Wu[29] were used according to the type of movement deficit experienced (Figures 3 and 4).

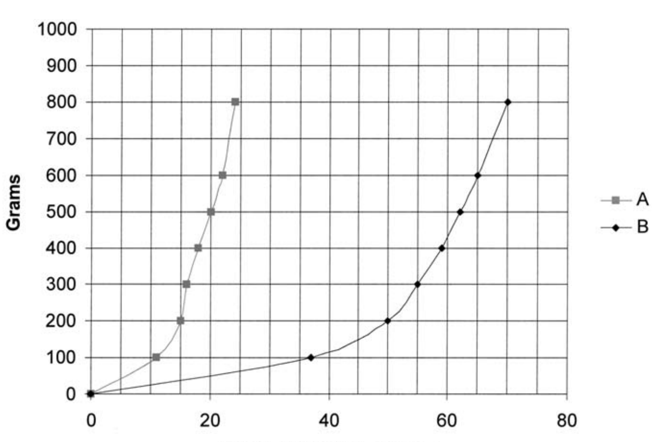


FIGURE 2. *TAC for the IP joint of two separate thumbs indicating (A) a more established contracture with a high degree of joint stiffness and (B) a contracture with a greater viscous component or "mild joint stiffness." The steeper the slope between 800 and 200 g, the stiffer the joint.*

Additionally, one subject with a flexion contracture of the MCP joint required a dynamic extension splint. These splints were chosen for two reasons: 1) The primary author had previously found them to be clinically effective, and 2) it was possible to monitor and control the level of force applied with these designs. Force was set at 200 g according to guidelines outlined by Brand and Hollister[10] and monitored weekly in therapy. It was paramount to control the amount of force applied to study successfully the impact of daily TERT. Subjects using splints with rubber-band traction were provided with a supply of size 12 bands and instructed to change these every two to three days. Additionally, these subjects were instructed not to flex or extend against the resistance of the rubber bands. All subjects were required to complete a splint diary, recording daily TERT.

Reliability Study

Reliability of the TROM technique was examined using the first 10 subjects in the sample. It was possible to achieve a pseudo-blind scenario for the therapist taking the TROM measurements by the following process. Therapist A positioned the subject's hand and the goniometer on the appropriate joint. Therapist A then applied the Haldex gauge at the correct point on the subject's finger and monitored the gauge until 500 g force was reached. Therapist B read the range of motion in degrees on the goniometer and recorded this, while therapist A continued to monitor the gauge ensuring the correct level of force was being applied. In this way, it was possible to blind the therapist taking the TROM measurements (therapist A) to the actual goniometric reading. This procedure was continued with two therapists completing TROM measurements for the first five subjects in the pilot sample as follows. Therapist A completed five consecutive TROM measurements followed directly by therapist B, who completed the same. After a 5-minute break,

FIGURE 3. A dynamic splint to assist PIP joint flexion. Fishing line passes through the outrigger from the sling and attaches to a rubber band via a dress hook. This is secured to the proximal portion of the splint via a Velcro tab.

therapist A completed a further five measurements followed by therapist B. For the second five subjects in the reliability study, the therapist order was reversed. This sequence of measurements allowed for all three forms of reliability to be investigated. According to the recommendations of Portney and Watkins,[22] it was necessary that test-retest measurements were conducted within the same session, as it was expected that TROM would improve from one session to the next.

Data Analysis

Intraclass correlation coefficients (ICCs) were used to study interrater, intrarater and test-retest reliability, whereas sequential clinical analysis (SCA) was used to study the primary research question of daily TERT. According to the usual procedure for SCA, subjects were paired chronologically as they entered the study: The first subject in group A was paired to the first subject in group B. Each pair of subjects was compared sequentially in relation to improvement in TROM over four weeks. An improvement in TROM of 20° or more was chosen as a clinically significant result. If the subject in group B improved 20° or more and the subject in group A did not, this resulted in a "preference" for B. Likewise a preference for group A resulted when the subject in group A achieved 20° or more improvement in TROM and the subject in group B did not. If both subjects failed to achieve an improvement in TROM of 20° or more, a "tie" was the result. If both subjects succeeded in improving 20° or more in TROM, the result was also a tie. A two-tailed sequential plan was plotted using the coordinates provided by Armitage for a significance level of 0.05, power of 0.95, and effect size of 0.75.[22] The expected effect size was estimated on the basis of clinical experience given the lack of previous research in this area. Preferences for each of the splint groups were plotted along the sequential chart according to the outcome for each pair. Ties were not included in the analysis as is the usual procedure for SCA. The potential impact of joint stiffness on final TROM was examined using a general linear model (GLM) procedure from SPSS version 8.0 for Windows (SPSS Inc., Chicago, IL). SPSS also was used to calculate ICCs and confidence intervals for the reliability analysis.

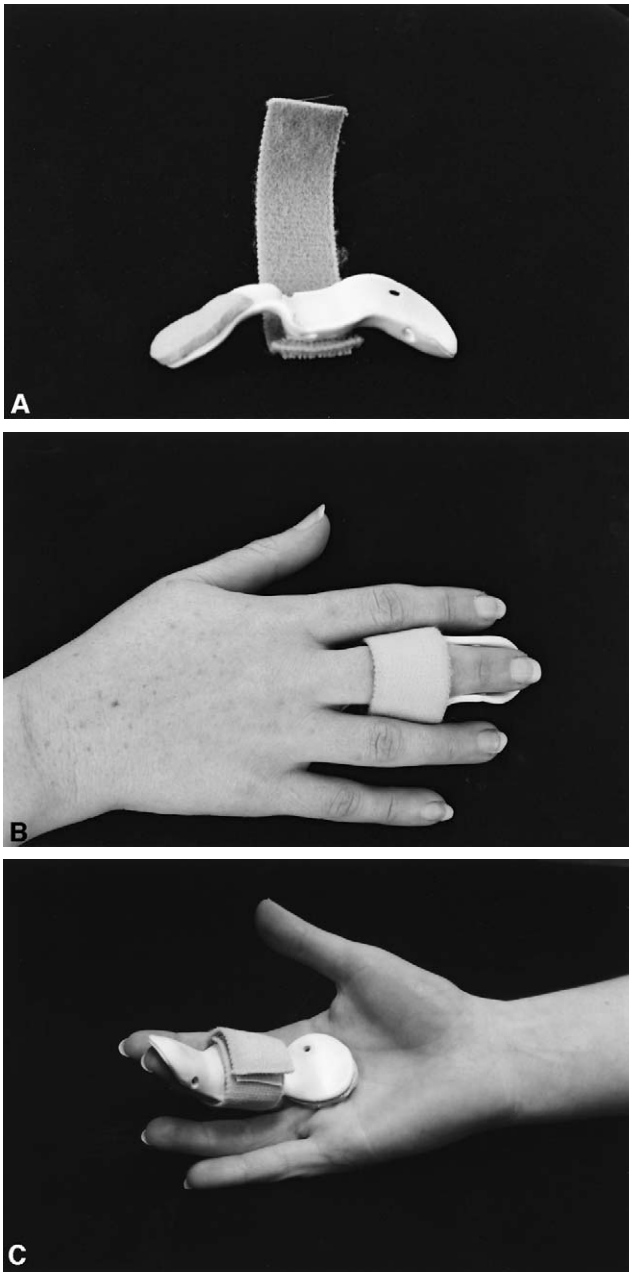


FIGURE 4. A modification of the "belly gutter" splint described by Wu[29] used to improve PIP joint extension. The volar surface of the splint is molded away from the PIP in a hump to create a space for the joint to be pulled into extension. An elasticized strap applies the mobilizing force.

TABLE 1. **Results of Reliability Study Using Intraclass Correlation**

Reliability	*Rater*	*Model*	*ICC*	*Lower CI*
Interrater	A and B	ICC (2,1)	0.9928	0.9838
Intrarater	A	ICC (3,1)	0.9932	0.9832
Intrarater	B	ICC (3,1)	0.9976	0.9941
Test-retest	A	ICC (2,1)	0.9938	0.9861
Test-retest	B	ICC (2,1)	0.9932	0.9847

RESULTS

Reliability Study

Results of the reliability study using the TROM technique are presented in Table 1. Interrater and test-retest reliability were examined using ICC model (2,1). Intrarater reliability was examined using ICC model (3,1) as recommended by Portney and Watkins.[22] The lower 95% confidence intervals are presented for each ICC as an estimate of the precision of measurement.

Baseline Data

Descriptive Characteristics of Subjects

A total of 43 subjects were recruited to the study, with 32 completing the four-week program. Table 2 outlines descriptive characteristics of the final sample of 32 subjects. Of the remaining 11 subjects who dropped out of the program, the major reason for failure to complete the study was nonattendance at therapy in six cases. This was considered to be a factor of the patient population and was consistent with previous clinical experience in the Australian public hospital system. Two subjects were unable to wear their splint due to low pain tolerance. This situation appeared to be associated with previously undiagnosed dystrophic features. Additionally, two subjects completed the study but failed to comply with their allocated splint program and crossed over into the alternative group. Results from these subjects were excluded from the final data set. One subject was excluded from the final sample because the treating therapist changed the goal of improving MCP flexion to improving MCP extension and ceased use of the dynamic flexion splint. Of the 11 subjects excluded from the final data set, 6 had been randomly allocated to group B (daily TERT 6 to 12 hours) and five to group A (daily TERT <6 hours).

Figure 5 outlines descriptive characteristics of the "dropout" group compared with those of the final sample. No large differences were evident between the two groups; however, the dropout group subjects were slightly younger and slightly less stiff than subjects in the final sample (36.8 versus 39.7 years; 14.5° versus 12.8° 800 to 200 g).

TABLE 2. **Descriptive Characteristics of Final Sample (*N* = 32)**

Sex	68.8% men
	31.2% women
Diagnosis	75% fracture-dislocation
	25% tendon/soft tissue
Joint	53.1% PIP
	25.0% MCP
	12.5% IP thumb
	6.3% MCP thumb
	3.1% DIP
Movement	71.9% flexion deficit
	28.1% extension deficit
Mean age in years (SD, range)	39.7 (13.5, 19–74)
Mean time* (SD, 95% CI)	9.7 (5.4, 7.7–11.6)
Mean stiffness† (SD, 95% CI)	12.8 (6.0,10.6–14.9)

*Time since original injury in weeks.
†Degree of stiffness measured using TROM technique (i.e., TROM at 800 g − TROM at 200 g = estimate of slope of torque angle curve (estimate of joint stiffness)). The higher the score, the lower pretreatment stiffness.

Descriptive Characteristics of Final Sample According to Group

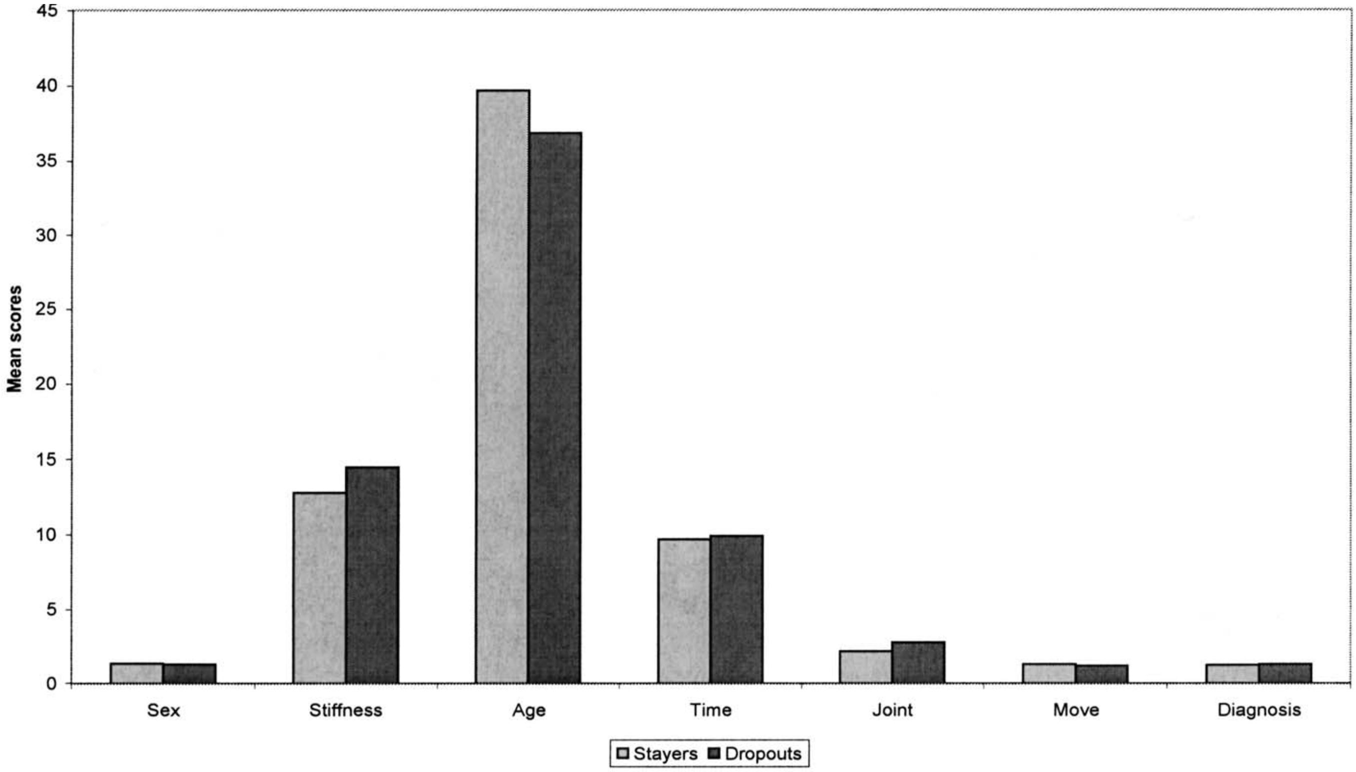
The final sample of 32 subjects contained 16 subjects in each of the two groups. Table 3 compares baseline data of the two groups.

Daily Total End Range Time and Contracture Resolution

The mean daily TERT for subjects in group A was 3.21 hours (range 0.62 to 5.48 hours). The mean daily TERT for subjects in group B was 7.87 hours (range 6.25 to 11.79). Sequential analysis was used to study the primary research question: the relationship between daily TERT and contracture resolution. The resulting sequential chart is presented in Figure 6 and indicates an overall preference for group B (daily TERT 6 to 12 hours). Eleven preferences were for group B, with one preference (the first point) for group A. Data from the four tied pairs were not included in the SCA but were examined separately as is the usual procedure with SCA.[22]

Tied Data

The four tied pairs comprised three pairs who failed to achieve a clinically significant result (i.e., failed to improve 20° TROM in four weeks) and one pair who did obtain a significant result. The pair of subjects who did achieve a clinically significant result was younger than the pairs who did not (mean age 23.5 versus 34.8). Other differences included a lower degree of pretreatment joint stiffness in pairs who failed to achieve a clinically significant result (14.5 versus 10.5) and a much lower mean change in TROM (11.0 versus 31.0).



Key	Stayers (Mean Score)	Dropouts (Mean Score)
Sex (1 = male, 2 = female)	1.31	1.27
Stiffness (average TROM °)	12.81	14.45
Age (average age in years)	39.69	36.81
Time (average time in weeks)	9.69	9.91
Joint (1 = MCP, 2 = PIP, 3 = MCP thumb, 4 = IP thumb, 5 = DIP)	2.16	2.73
Move (1 = flexion, 2 = extension)	1.28	1.18
Diagnosis (1 = fracture-dislocation, 2 = soft tissue)	1.25	1.27

FIGURE 5. *Mean score comparison of subjects who failed to complete the study ("dropouts") with final study sample ("stayers").*

Baseline characteristics of tied and untied pairs were compared using descriptive analysis and revealed only minor differences. Untied subjects were found to be slightly older than tied subjects (41.04 versus 35.63) and had a greater percentage of soft tissue injuries rather than fracture-dislocations (i.e., untied 66.7% fracture-dislocation versus tied 100% fracture-dislocations). Figure 7 compares tied and untied subjects on baseline characteristics.

Pretreatment Joint Stiffness, Joint Type, and Contracture Resolution

The relationship between degree of joint stiffness and final TROM (hypothesis two) was studied using a GLM. GLM allows for the main and interaction effects of important factors to be studied, after the dependent variable is adjusted according to a known covariate. Pretreatment joint stiffness was the known covariate in this study and TROM the dependent variable. Group A versus B (i.e., daily TERT) was the main effect to be studied, and joint type was included in the model as an interaction effect. Joint type was included because according to baseline data, there was a difference between the two groups on this factor after randomization. Group B had a higher percentage of PIP joints than group A (group B 75.0%, group A 31.3%) (Table 3). Joints were collapsed into two primary categories to allow sufficient numbers in each category for analysis. The first category included all MCP joints of the fingers. The second category included PIP and DIP joints of the fingers and the MCP and IP joint of the thumb. The decision to categorize joints in this manner was based on literature suggesting that the MCP joint of the thumb behaves more like a hinge joint, with much

TABLE 3. **Comparison of Groups According to Baseline Data**

	Group A (Daily TERT <6 hours) (n = 16)	*Group B (Daily TERT 6–12 hours) (n = 16)*
Sex	68.8% men 31.2% women	68.8% men 31.2% women
Diagnosis	75% fracture-dislocation 25% tendon/soft tissue	75% fracture-dislocation 25% tendon/soft tissue
Joint	31.3% MCP 31.3% PIP 25% IP of thumb 6.3% MCP of thumb 6.3% DIP	18.8% MCP 75.0% PIP 0% IP of thumb 6.3% MCP of thumb 0% DIP
Movement	93.8% flexion deficit 6.3% extension deficit	50% flexion deficit 50% extension deficit
Mean age in years (SD, range)	39.7 (14.7, 19–73)	39.7 (12.7, 27–74)
Mean time in weeks* (SD, 95% CI)	10.9 (6.6, 7.3–14.4)	8.5 (3.6, 6.6–10.4)
Mean stiffness† (SD, 95% CI)	14.6 (4.4, 12.3–16.9)	11.0 (7.0, 7.3–14.7)
Worker's compensation	5 subjects	6 subjects

*Not significant, p = 0.219.
†Not significant, p = 0.09.

less lateral movement than that found in the MCP joints of the fingers.[30,31] Overall the model was significant ($F_{(3,28)} = 3.71$, $p = 0.023$). The only statistically significant predictor was group ($p = 0.005$) with pretreatment joint stiffness ($p = 0.162$) and joint type ($p = 0.463$) nonsignificant. The marginal mean for group A after adjustment for joint type and stiffness was 10.2 and for group B was 21.9.

DISCUSSION

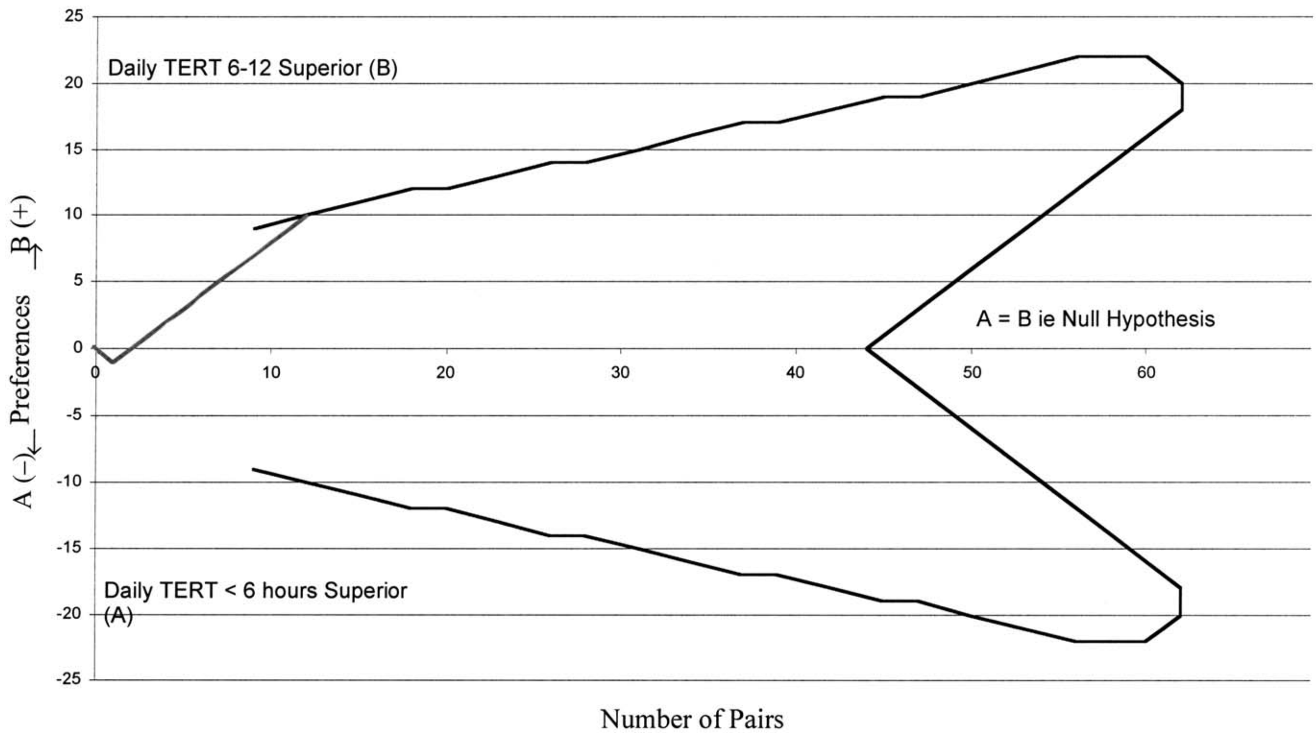
The importance of daily TERT in efficacy of contracture resolution was examined as the primary research aim of this study. Pretreatment joint stiffness was also explored as a key variable expected to influence outcome. Findings indicate a strong preference for a daily TERT of greater than six hours per day and suggest that pretreatment joint stiffness and joint type were not strong predictors of final TROM, for this study sample. The high reliability of the TROM technique was shown, which is consistent with findings from most related literature.[15,25,32]

Limited research is available against which the baseline characteristics of this sample can be compared. General characteristics appear consistent, however, with clinical experience in a large Australian public hospital (e.g., 68.8% male, 31.2% female). Additionally, there were minimal differences between subjects who dropped out of the splint program and subjects who went on to become part of the final study sample (Figure 3). The discovery that the PIP joint was the most common joint involved in this sample (53.1%) is consistent with findings in the clinical setting. Much of the literature on splinting for contracture resolution has focused on PIP joint deficits in the past, suggesting the clinical significance of these contractures.[1,15–17,33]

An important difference was found between group A (daily TERT <6 hours) and group B (daily TERT 6 to 12 hours) in relation to joint distribution indicating that randomization had not been completely successful. Of subjects in group B, 75% had contractures involving the PIP joint (flexion and extension) versus 31.3% in group A. Group A had an equal number of contractures involving the MCP joint (31.3%). Additionally, differences were found between the two groups in relation to the type of movement deficit experienced (i.e., flexion-extension contracture). On review, it became apparent, however, that the type of movement deficit experienced by an individual subject was a factor of the particular joint involved. Traumatic injuries involving the MCP joint frequently are associated with reduced passive flexion rather than extension, whilst PIP joint injuries more commonly involve both passive flexion and extension deficits. The greater percentage of extension deficits in group B is likely to be associated with the greater number of PIP joints in this group. It was not possible to perform any further comparative baseline analysis of the two groups according to movement deficit because of insufficient numbers in each category.

As a result of differences in joint type across groups, differences also were found in relation to the type of splint used. Subjects in group A used dynamic splints incorporating rubber-band traction to address their joint contractures (15 dynamic flexion assist splints and 1 dynamic MCP extension splint). Subjects in group B had used a combination of rubber-band traction and the modified belly gutter (10 dynamic flexion splints and 6 modified belly gutters). Despite this difference, further comparison of subjects within group B revealed that the average increase in TROM was 21.7° for subjects using a modified belly gutter splint versus 22.3° for subjects using dynamic flexion splints. It was not possible to analyze this difference further due to insufficient numbers within each splint category. It appeared unlikely, however, that such a small difference had significantly influenced study findings.

A GLM procedure was used to study the potential significance of the difference in joint distribution between groups and the importance of pretreatment stiffness. Results indicated that joint type was not a significant factor influencing the degree of contracture resolution/final TROM ($p = 0.463$). Pretreatment degree of joint stiffness was also not found to influence final TROM significantly ($p = 0.162$). This supports the findings of Prosser[16] in her study of PIP

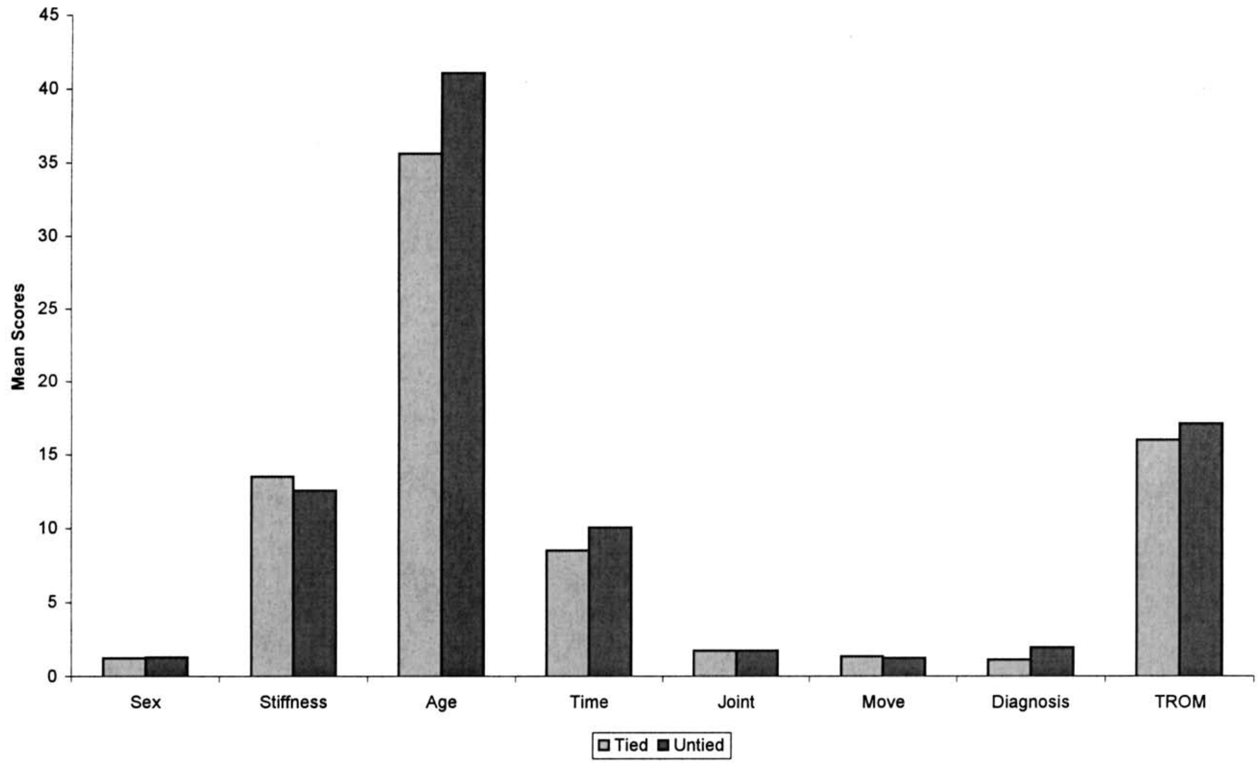


Pair	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
Preference A (TERT <6)	A															
Preference B (TERT 6-12)		B	B	B	B	B			B			B	B	B	B	B
Tie (no preference)							T	T		T	T					

FIGURE 6. *SCA chart of preferences for daily TERT.*

joint flexion contractures, yet conflicts with the findings of Luster et al.[18] in their study of MCP extension contractures after burns. Luster et al.[18] found that pretreatment joint stiffness did influence contracture resolution, whereas daily TERT did not. Luster et al.[18] had a sample size of only four subjects (20 stiff MCP joints), however, and daily TERT varied from either one hour once a day to one hour twice a day. Treatment was for three days only, and follow-up measurements at six days indicated a return to pretreatment joint stiffness. An electronic device was used to measure pretreatment joint stiffness in contrast to the TAC technique used in the current study as well as in that of Prosser.[16] Hence, systematic differences in study design and measurement techniques do not allow for direct comparison of findings between these three studies. Additionally, the small sample sizes used in all three studies render it impossible to exclude the potential for type II errors due to power limitations. It was possible only to conclude that for the daily TERT sample in the current study, pretreatment joint stiffness ($p = 0.162$) and joint type ($p = 0.463$) did not *strongly* influence final TROM. Further research is necessary, however, to clarify in particular the role of pretreatment joint stiffness in contracture resolution for the wider population of patients experiencing traumatic upper limb injury.

The results of the SCA indicate an overwhelming preference for group B (daily TERT 6 to 12 hours) and support the notion frequently cited in the literature that low load prolonged stress is preferable in splinting for contracture resolution.[7–10,34] Findings support the general premise of TERT theory—that the extent of contracture resolution is proportional to end range time. With a daily splint use of eight hours rather than three hours, the overall TERT at the end of four weeks is much greater (224 hours versus 84 hours). By achieving a greater treatment dosage within the same time frame, subjects in group B achieved a greater degree of contracture resolution. However, the exact nature of the relationship between TERT and contracture resolution (i.e., linear/nonlinear) remains unclear, as does the optimal splint duration. The earlier work of Prosser[16] would suggest that an average of at least four months is required. Further research is required to clarify these issues.



Key	Tied Data (Mean Score)	Untied Data (Mean Score)
Sex (1 = male, 2 = female)	1.25	1.33
Stiffness (average TROM °)	13.5	12.58
Age (average age in years)	35.63	41.04
Time (average time in weeks)	8.5	10.08
Joint (1 = MCP, 2 = PIP, 3 = MCP thumb, 4 = IP thumb, 5 = DIP)	1.75	1.75
Move (1 = flexion, 2 = extension)	1.38	1.25
Diagnosis (1 = fracture-dislocation, 2 = soft tissue)	1.13	1.96
TROM (change in TROM over 4/52)	16	17.13

FIGURE 7. *Mean comparison of tied and untied subjects.*

The relative importance of time since injury also needs to be considered. Although there was no significant difference in time since injury between subjects in group A and group B in this study, the question remains: Are subjects who start a splint program at four weeks postinjury likely to show greater gains in contracture resolution than subjects who start a splint program at 12 weeks? Previous studies have been unable to show conclusively a relationship between time since injury and contracture resolution.[16]

Limitations of the Study

Study Design and Internal Validity

The SCT design has some advantages for a study of this nature in an area that lacks prior research. SCT allows for results to be analyzed as the study progresses, and this has some important ethical implications. If it becomes apparent early in the data collection phase that the new treatment is no different or is worse than the standard treatment, the trial can be stopped immediately without further inconvenience or harm to subjects. Additionally, the SCT design helps to overcome the problem of small sample size frequently encountered in hand therapy research. Incidences of specific conditions and diagnoses in hand therapy are frequently small compared with other fields of research. The use of multivariate statistical analyses to address clinical issues results in an increased chance of type II errors. That is, the chance of falsely accepting the null hypothesis is higher than usual because of insufficient power of the study. SCA does not require large numbers of subjects in order to obtain a significant/nonsignificant result and is particularly suitable for pilot studies or research in the clinical setting.[22]

There are some limitations to the SCT design that may pose a threat to the internal validity of the daily TERT study. It is not possible to control for extraneous variables, such as degree of pretreatment joint stiffness, age, or time since injury using this approach. The use of a randomization procedure is crucial along with careful evaluation of baseline characteristics, using supplementary analyses.

The use of a single-blind rather than a double-blind design also has the potential to influence the validity of the findings of the daily TERT study. It was not feasible to implement a double-blind technique in the clinical setting of this study because the primary author was responsible for completing initial assessments for all subjects. This was the case for several reasons. First, caseload requirements in a busy public hospital limited the amount of assistance that could be provided by coworkers. Second, it was not always possible to access the support of other therapists due to the location of separate workstations in different buildings on the hospital campus. Therefore, despite attempts to minimize bias with the use of random allocation to treatment groups, subject blind and a standard treatment program, the potential for experimenter bias remains a limitation of the study.

Another issue that requires consideration is the use of a self-report technique to measure daily TERT. Subjects were required to monitor the length of time they wore their splints each day and record this on a splint diary sheet. According to Schecter and Herrmann,[35] four cognitive processes are involved in the process of self-report and include comprehension of requirements, recall and memory search, decision making with regards to response options, and execution of the actual response. The potential for breakdown at any one of these levels may pose a threat to the validity of the responses in this study. Validity may be threatened due to poor recall or poor or dishonest recording.

Information about the subjective experience of subjects in group B versus group A was not collected formally. It was acknowledged, however, that subjects in group B (daily TERT 6 to 12 hours) generally found it more difficult to meet daily TERT requirements than subjects in group A (daily TERT <6 hours). This was particularly true for subjects who were unable to tolerate splints overnight.

External Validity

Another important issue to consider with SCA is the effect of ties. Tied data are not plotted on the sequential chart. In a study that contained many ties, it would not be possible to assume that the untied pairs remained representative of the original random sample. The external validity of the study would be compromised, and it would not be appropriate to generalize the findings to the population being studied. In the daily TERT study, 11 pairs had a preference for B (daily TERT 6 to 12 hours) and one for A (daily TERT <6 hours) with four ties. Armitage[36] warned readers against the problem of ties when using sequential plans; however he did not provide guidelines as to an acceptable/unacceptable number. The four ties out of 16 possible pairs found in the results of this study do not seem excessive when viewed together with the overwhelming preference for group B (daily TERT 6 to 12 hours). Tied subjects were not remarkably different in presentation on descriptive baseline characteristics than untied subjects (Figure 7).

Recommendations

Limitations of the daily TERT study have been discussed. The need for further research to substantiate findings is warranted due to problems associated with small sample size and difficulty controlling for potential confounding variables through randomization and use of the sequential design. Additionally, further research is needed in the following areas:

- To consider the possibility of an optimal daily TERT within or beyond the 6- to 12-hour range. Is a daily TERT of 10 hours better than 8 hours? Is a daily TERT of 14 hours better than 12 hours? Kolumban,[17] in a 1969 study of daily TERT and contractures of PIP joints, concluded that there was no significant difference between a daily TERT of 22 hours or 11 hours ($p = 0.38$). No further study of daily TERT greater than 12 hours per day has since been conducted.
- To investigate the question of intermittent versus continuous splinting. The current study grouped subjects into two general time frames with the aim of providing some preliminary guidelines for therapists. Subjects who wear splints for longer periods may also be more likely to wear these continuously (e.g., overnight). Ideally, this factor should be examined in future research.
- To investigate the reliability and aspects of validity of the TAC technique as a measure of joint stiffness after traumatic hand injury. Some research has been conducted using normal joints, however, not following traumatic injury.[26,28]

The importance of other variables, such as time since injury and diagnosis, requires further study as well as the question of the optimal duration of splint programs.

CONCLUSIONS

The findings of this research indicated that for the study sample, a daily TERT of greater than 6 hours per day facilitated contracture resolution at a faster rate than a daily TERT of less than 6 hours a day, over four weeks of splinting.

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