Splinting in the Management of Proximal Interphalangeal Joint Flexion Contracture

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ABSTRACT: Proximal interphalangeal (PIP) flexion contracture is a common complication following hand injuries and conditions. This study investigated the treatment outcome of 20 subjects with PIP flexion contracture who followed a dynamic splinting program using either a Capener or low-profile outrigger. The splint applied a 250-g force to the distal end of the middle phalanx. Each patient was instructed to wear the splint for 8 to 12 hours per 24 hours for 8 weeks followed by a 2- to 3-week weaning period. Passive extension was evaluated objectively using torque range-of-motion measurement. The average pretreatment flexion contracture was 39°. Final extension deficit averaged 21°, an improvement of 18°. There was no statistically significant effect on final results based on joint stiffness (as expressed by the slopes of the torque angle curves). Total end-range time (TERT) averaged 10 hours per 24 hours, for an average period of 4.3 months. Statistical analysis showed that splinting time was the only statistically significant factor affecting outcome. The correlation coefficients showed that the longer the contracture was present, the stiffer the joint and the less the contracture resolved. Dynamic splinting was an effective form of treatment for PIP flexion contracture.


The proximal interphalangeal (PIP) joint and its motion are among the most important factors in hand function. Without PIP joint motion, a functional grip cannot be made. The PIP joint is responsible for 85% of total encompassment when grasping an object compared with the distal interphalangeal (DIP) joint, which is responsible for only 15%.1 If the PIP joint cannot flex then activities involving handling and maintaining grasp on medium to small objects, particularly cylindrical objects, is very difficult. If the PIP joint cannot fully extend, then extension in preparation for grasp is limited, and large objects cannot be gripped. Lack of PIP extension can also hinder other functional activities, such as washing the face and putting the hand in a pocket.

A PIP joint flexion contracture is described as the inability to passively extend the joint to neutral. Without passive extension, active extension cannot be achieved, causing the functional deficit described. A frequent complication following PIP joint trauma is PIP joint flexion contracture. PIP flexion contracture may also occur as a consequence of poor positioning of the joint during immobilization.2 Injury to the PIP joint often involves rupture of the joint's stabilizing structures, most commonly the volar plate (VP) and collateral ligaments. Ake son et al.3 have reported on the changes in the tissues as a flexion contracture develops. The longer the joint is flexed, the more mature is the fibrous structure of the healing tissues. As the collagen matures and forms more anomalous cross links, the functional gliding of the tissues decreases. The longer these cross links and adhesions are present, the more mature and less malleable they become, and the longer the contracture is present, the stiffer the joint.

Treatment for PIP flexion contracture can be conservative, using exercise and splintage alone, or it can be surgical. Many authors4-7 have described conservative management using splinting for this joint problem, including static digit or hand-based splints, as well as dynamic digit, hand-, or forearm-based outrigger splints. Most studies do not give complete descriptions of the splints used and the exact splinting program.2,5 Callahan and McEntee7 report on the criteria for splint usage; however, they do not describe splint usage in a subject population or their results. Kolumban4 does report on the outcome of static and dynamic splinting with objective joint stiffness measures of 13 subjects in an Indian population in whom PIP flexion contracture was due to leprosy.

The literature does not describe the quality of joint stiffness, objective measurements of passive extension in PIP flexion contracture secondary to trauma, and how this is altered with a specific splinting program in a clinical setting. This study attempted to look at these parameters.

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METHOD

The study arrived at the following hypotheses:

1. There is no association between splintage time and final extension (i.e., resolution of contracture).
2. There is no association between time of contracture before treatment to splintage time and final extension (i.e., resolution of contracture).
3. There is no association between initial stiffness to splintage time and final passive extension (i.e., resolution of contracture).
4. There is no association between initial stiffness and final stiffness.

SUBJECTS

Twenty subjects with PIP flexion contracture of 25° or more were assessed and treated prospectively. All subjects were referred to the Sydney Hand Therapy and Rehabilitation Centre specifically for splintage of the PIP joint for flexion contracture. Subjects with flexion contracture of more than 6 months' duration, with more than two PIP joints involved, with the diagnosis of an inflammatory joint condition such as arthritis, or assessed by the surgeon and therapist as requiring surgery, were excluded.

The study group comprised five females and 15 males. The average age was 35 years (SD: 13). The contracture was present for 12.8 weeks (SD: 7.9) on average. The subjects were allocated into one of two groups. Ethical considerations in the light of the present literature by Callahan and McEntee influenced the author to allocate subjects with a contracture greater than 45° to group 2. This was an ethical constraint and limited the study. All other subjects were randomly allocated to either group. Eleven digits were treated with a Capener splint (group 1), and 11 others were treated with a low-profile outrigger splint (group 2).

DATA COLLECTION

Age, gender, hand dominance, injured hand, diagnosis, type of injury, length of time of flexion contracture, the number of digits affected, and the tissues deemed to be involved were recorded from subject interview and physician referrals. Passive extension was assessed with torque range of motion (ROM) as described by Brand and Hollister and by others. Torque ROM procedure for this study involved maintaining the wrist in the neutral position and the metacarpophalangeal (MCP) joint in flexion. A force of 800 g was applied at right angles to the middle phalanx 3 cm from the PIP joint, and the resultant ROM was measured (Fig. 1). All measurements were done by the author.

The subjects were assessed before the splint was applied and then again at 2, 4, 8, and 12 weeks. Further measurements were made at 16, 20, and 24 weeks if it was deemed necessary to continue splintage for longer than 8 weeks. The data were statically analyzed with Pearson's product moment correlation coefficients, multiple regression analysis of variance, and repeated measures multivariate analysis of variance (MANOVA).

SPLINTAGE PROGRAM

A Capener splint was custom made for each of ten subjects. The digit-based Capener splint has two coil springs on either side of the joint. These produce the extension force illustrated in Figure 2. The remaining ten subjects had a custom-made, low-profile, hand- or wrist-based outrigger splint with rubber band traction, as illustrated in Figure 3. This splint is referred to as the outrigger splint.

Both splints were adjusted to apply a force of 250 g at the distal end of the middle phalanx to the joint with the PIP flexion contracture. The splint force was checked and adjusted if necessary at each assessment session. The force applied by the Ca-
A hand-based, low profile, outrigger splint uses rubber-band traction as the extension force acting on the PIP joint. The proximal metacarpophalangeal joint is stabilized by the thermoplastic component.

Capener splints was measured by using a method described by Fess.13 A Haldex gauge was applied to the distal thermoplastic band of the splint; pressure was then applied through the Haldex gauge to the splint until the thermoplastic band touched the middle phalanx. The force shown on the Haldex meter, being the force applied by the splint, was then recorded. If the resultant force was greater than 250 g, the lever arms were adjusted into enough flexion to reduce the force to 250 g. The force of the low-profile outrigger was measured using a Haldex gauge applied to the end of the rubber band traction.

The subjects were instructed to wear the splint for 8 to 12 hours every day for 8 weeks. The subjects were encouraged to wear the splint while sleeping and for several hours while awake. This freed the hand for functional use for most of the day. Each subject recorded a log sheet of the time the splint was worn. After 8 weeks, the subject was weaned from the splint over a 2- to 3-week period. This time was included in the total splint-wearing time. If the subject reported a loss of more than 5° in extension when the splint was not worn, then the time of splintage in weeks was extended until extension could be maintained without splintage. All subjects were instructed to perform active flexion and extension of the PIP joint (10 repetitions) and blocked PIP extension (10 repetitions) four times per day (24 hours).

ASSUMPTIONS

An acceptable reliability in joint ROM measurement was assumed. The measurements were undertaken by the same therapist, who was experienced in this method of measurement. Flowers and LaStayo14 and others15 report good intrarater reliability for an experienced therapist. The subjects' splint-wear time reports were assumed to be honest and accurate.

RESULTS

All patients with PIP flexion contracture treated with splintage (either Capener or outrigger) improved. No flexion contracture completely resolved; that is, complete extension was not achieved. The outcome of treatment was evaluated clinically and statistically with Pearson's product moment correlation coefficients, multiple regression analysis of variance, and repeated measures MANOVA with initial extension and splint wear as covariates. The two splint types were not significantly different in their performance according to a repeated measures MANOVA with initial extension and splint wear as covariates. In view of this, data were analysed for the total sample only.

TOTAL SAMPLE RESULTS: CLINICAL RESULTS

Characteristics of Subjects

The total sample size was 20: five female and 15 male subjects, with 22 digits being treated. Eleven subjects had flexion contracture of the dominant hand and nine subjects of the nondominant hand. The little and ring fingers were predominantly affected: ten subjects had a little-finger flexion contracture, ten had a ring-finger flexion contracture, only one had middle-finger flexion contracture and one index finger flexion contracture. The most common injury causing the contracture was a joint injury: 11 digits. Joint and tendon injury was the next most common: eight digits, six involving extensor tendons and two flexor tendons. Joint, tendon and bone, and joint and bone injuries accounted for three digits.
Extension Outcome: Final Passive Extension Deficit

The initial and final passive extension 0.24 Nm (800 g at 3 cm) can be seen in Graph 1. The average pretreatment contracture was 39° (SD: 10) passively at 0.24 Nm. Maximum extension range achievable with splintage was deemed to have occurred when the extension torque ROM curve remained unaltered over 4 weeks. No subject's flexion contracture completely resolved. The final passive extension achieved averaged 21° (SD: 10).

The average improvement in passive extension can be seen in Graph 2. After 2 weeks of splinting, there was an average improvement of 14° (SD: 11). Final average improvement was 18° (SD: 9).

Torque ROM

Stiffness as indicated by the slope of the torque curve (Graph 3) did not appear to have any influence on the final outcome. The average torque ROM was 11° per 800 g (SD: 6) presplintage and 9° per 800 g (SD: 4) postsplintage.

Compliance and Splinting Time (TERT): Splint Wear and Splint Duration

All subjects required splintage longer than 8 weeks to ensure that passive extension had plateaued. Compliance to wearing time in every 24 hours ranged from 6 to 14 hours. Seven subjects wore their splints 6 to 7 hours on average in every 24 hours. Eleven wore their splints for an average of 8 to 12 hours per 24 hours. Four subjects wore their splint for an average of 13 to 14 hours per 24 hours. Mean TERT in terms of splint wearing time was 10 hours per 24 (SD: 3). The average TERT in terms of splintage duration was 4.3 months (SD: 1.8).

Tissues Injured

There was no clinical difference among those who were deemed to have joint injuries alone (11 subjects), those with joint and tendon injuries (eight subjects), and those with joint and bone injuries (three subjects). It is not possible due to the small sample size to make any statistically significant statements with regard to the effect of the tissues injured on the final extension achieved. However, subjects with joint injuries alone had an average passive improvement of 19° (SD: 8). Joint and tendon injuries average passive improvement was 17° (SD: 10); joint and bone, and joint, tendon, and bone injuries had 15° (SD: 12) average passive improvement. All structures around the joint are closely related, as was described previously. It is therefore difficult to say if the tendons were or were not involved via adhesions, flexor sheath injury, or ORL injury in the joint-only group.

### TOTAL SAMPLE RESULTS: STATISTICAL ANALYSIS

Association between Variables

The correlation coefficient matrix showed that there was some interaction between the variables (Table 1). The most significant correlations (i.e., p = 0.01 were:

1. The initial extension was related to the final extension. The higher the initial extension, the higher the final extension deficit.
2. The initial stiffness was related to the final extension. The stiffer the joint, the greater the final extension deficit.
3. The initial stiffness was related to the final stiffness. The joints that were stiffer initially were also stiffer after treatment.

Significant correlations at the lower p level (i.e., p = 0.05) were:

1. Initial stiffness was related to initial extension. The greater the flexion contracture, the stiffer the joint.
2. Final stiffness was related to splinting duration. The greater the stiffness, the longer the duration of splintage.
3. Contracture time was related to initial stiffness. The longer the contracture time, the stiffer the joint.

Multiple regression analysis of variance was done using the following variables: final passive extension, splint wearing time per 24 hours and splinting duration (TERT), initial passive extension, contracture time, final stiffness and initial stiffness. When final passive extension is the dependent variable and all others are independent variables, initial extension deficit and splinting time (TERT) in terms of splinting duration are the only variables influencing final extension. When final stiffness is the dependent variable and all others independent, there is a significant linear relationship between final stiffness and initial stiffness. Initial passive extension also had an influence on final stiffness. When splinting time (TERT) is the dependent variable and all others are independent variables, the longer the duration of splintage, the greater the final stiffness. No other variables, including contracture time and initial stiffness, influenced splinting time (TERT).

DISCUSSION

Associations between Splintage Time (TERT) and Final Extension

The statistical analysis showed that there is an association between splinting time (TERT) and final extension. Following 3 to 5 months of splintage for both groups, the contractures resolved passively from 39° to 21° on average, an increase in extension of 18°. This compares favorably with Kolumban's 1969 results. He reports an average increase in extension of 10.3° with static splinting, and an average increase of 7.9° with dynamic outrigger splinting (profile not specified) of 6 weeks' duration for flexion contracture due to leprosy. Kolumban did not report on longer term follow-up or the extent to which the improvement reported was maintained. In this study, the minimum follow-up was 3 months; maximum follow-up was 14 months. Kolumban also reports some injury to the subjects from outrigger splintage. There were no injuries due to either splint type in the present study.

Several patients lost extension once they stopped splintage. Those who reapplied their splints regained the lost extension and were able to maintain it with a greater splinting duration. Passive extension cannot be maintained if there is inadequate active extension. It has already been established that the joint tissues respond to the tension placed on them. If there is inadequate extension force, the tissues will respond by tightening and ultimately shortening. Thus, once the splintage is discontinued, extension needs to be maintained in the long term by active motion.

Associations between Time of Contracture and Final Extension

The hypothesis that there is no association between time of contracture before treatment to splintage time and final extension is supported by the multiple regression analysis of variance, but it is not supported by the correlation coefficients. Time of contracture did correlate with initial stiffness (p = 0.05). The longer the contracture was present, the stiffer the joint became. A stiffer joint initially was associated with a greater extension deficit. The conflict in statistical data may be confounded by the small sample size and the lack of a homogeneous population.

The correlation coefficients show an association between the initial flexion contracture and final ex-

<table>
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<th>Variable</th>
<th>Splint Duration</th>
<th>Initial Extension</th>
<th>Final Extension</th>
<th>Contracture Time</th>
<th>Initial Stiffness</th>
<th>Final Stiffness</th>
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*Significant at the p = 0.05 level.
**Significant at the p = 0.01 level.
Initial extension = initial passive extension (0.24 Nm).
Final extension = final passive extension (0.24 Nm).
Contracture time = contracture time before splintage.
Splint wear = splint wearing time per 24 hours.
tension deficit. This can be seen in Graph 4, in which initial extension is plotted against final extension. It also supports the clinical observation that a more contracted joint does not improve as much as a joint with a lesser contracture. Akeson et al. have reported on the changes in the tissues as a flexion contracture develops. Cross links and adhesions become more mature and less malleable the longer they are present. The longer the contracture is present, the stiffer the joint.

It could be argued that, when the joint has a greater contracture, more tissues are involved, and this may require more force than can be safely placed on the soft tissues in order for the tissues to alter their structure and elongate. There may also have been structural changes in the tissues that will not respond to a safe extension force (0.24 Nm in this study).

Associations between Splinting Time (TERT), Compliance and Extension

Flowers and LaStayo report that the amount of increase in passive ROM in a stiff joint is in proportion to the amount of time the joint is held at its end range or TERT. In a group of 20 subjects with flexion contracture treated with plaster cylinder casts, Flowers and LaStayo report that TERT was the most significant factor in increasing passive extension. In terms of splinting duration, TERT was the most statistically significant factor in increasing extension in this study. All subjects required prolonged splinting to both achieve and maintain the extension gains. All required a weaning off period, ranging from 2 to 8 weeks. The prolonged splinting requirement supports the rationale that the tissues need to be under tension long enough for synthesis of new collagen and covalent bonds.

Previous authors have suggested a daily splint wearing time of 8 to 11 hours in every 24 hours over an extended time. Average splinting time in hours for the total group was 10 per 24 (SD: 3); the Capener group was 11 per 24 (SD: 3), and the outrigger group was 8 per 24 (SD: 2). Most of those subjects who wore the outrigger did report that, subjectively, they found it difficult to wear the outrigger during the day because it interfered with their hand function. Compliance with day wear and splinting duration for the Capener group was better; most subjects reported that they did not really mind wearing the splint in the daytime. A Capener splint is much smaller and does not cover as much of the hand as an outrigger splint does. It is the author's clinical impression that splint size is a strong factor in regard to compliance.

Watson and Turkeltaub and Snell and Conolly recommend, from clinical experience alone, a splinting duration of 3 months. Results from this clinical investigation suggest that a splinting duration of 4.3 months on average should be recommended. Splinting duration ranged from 2.5 to 10 months. The correlation coefficient suggests that the greater the splintage duration, the greater the resolution of the contracture (i.e., the lower the final extension deficit).

Thirteen of the 22 digits (60%) treated and evaluated in this study required splinting for longer than 3 months. Two subjects required splinting for longer than 5 months. One subject had a very inflamed joint when splinting was commenced. The prolonged inflammatory phase required the tension of the splint to be reduced to 100 g–150 g in order to prevent aggravation and further inflammation of the joint. Once inflammation was controlled, the splintage force was increased to 250 g. The prolonged inflammatory phase influenced time to remodeling and collagen tissue remodeling itself. The other subject had a long-standing contracture, as did several other subjects. Some of these subjects improved in a relatively short time (3 months). (Perhaps the nature of the healing tissues and the scar of each individual govern how quickly the soft tissues respond). The fibrous tissue restricting the joint may be more mature and less fibroplastic, with more fibrin strands and covalent bonds requiring a greater time for tissue lengthening.

Associations between Rate of Extension Improvement, Initial Extension and Splinting Time (TERT)

Clinical observation of rate of improvement for the two groups was different (Graph 5). For the Capener group, in whom initial passive extension deficit ranged from 22 to 43°, average improvement at 2 weeks was very similar to the final improvement achieved (at least 90% of final average improvement). For the outrigger group, in whom initial passive extension deficit ranged from 24 to 65°, there was a 65% average improvement at 2 weeks compared with the final average improvement. No conclusion can be drawn from these data; the two groups could not be compared statistically due to the differences in initial flexion contracture.

This observation on rate of improvement is interesting. The differences in contracture severity or
According to the correlation coefficient, greater initial stiffness was associated with greater final stiffness. The joints that were the stiffest before treatment were also the stiffest after treatment. This does reflect the clinical situation. The fourth hypothesis, that there is no association between initial and final stiffness, is therefore rejected.

Subjects with a steep torque curve slope (less than 10° per 800 g) were classified as having non-springy joints, these joints being the stiffer ones. Those with a flatter torque curve slope (10° or greater per 800 g) were classified as springy or not as stiff as non-springy joints. Some of the stiffer joints showed a flattening of their curve within 2 weeks of splintage, indicating that the joint was becoming more springy. The early flattening and improvement of the torque curve slope suggest that the fibrin strands in the healing injured soft tissues may be in a fibroplastic phase, where they could be remodeled by alterations in water content and the extracellular matrix to produce a longer structure.

Data from this clinical study do not support Callahan and McEntee's premise, based on clinical experience alone, regarding springy and non-springy joints. Callahan and McEntee suggest that the joint is springy if it improves 10 to 15° in the first week of splintage and non-springy if it only improves 5 to 10° in that time. Of the subjects with stiff joints (i.e., torque curve slope of less than 10° per 800 g), some improved less than 10° and others improved more than 10° in the first 2 weeks of splinting. No factor explained or identified the reason for this difference.

RECOMMENDATIONS FOR FURTHER RESEARCH

This study indicated that there is an association between splinting time and final extension deficit and there is an association between initial and final stiffness. Further investigation with a larger, more homogeneous sample is necessary to confirm the findings of this clinical study. The two associations in which the statistical data were conflicting also

TERT rather than differences in splint types may be the most important factor affecting rate of improvement. Both splints provided a 250-g extension force at 90° to the distal end of the middle phalanx. In this study, the Capener splint group clinically had a better TERT time than the outrigger group did (Graphs 6, 7), suggesting that a Capener splint may be more effective in the clinical situation than the outrigger splint. Further research with two groups matched in flexion contracture and randomly allocated to either Capener or outrigger splint groups needs to be undertaken before any conclusions can be drawn regarding rate of improvement, splint types, TERT, and compliance.

Associations between Initial Joint Stiffness, Splinting Time, Final Extension, and Final Joint Stiffness

Multiple regression analysis of variance suggests joint stiffness, as measured by torque ROM curve slope, did not affect the final passive extension achieved (Graph 3) or the splinting time. The third hypothesis of this study, that there is no association between initial stiffness to splintage time and final passive extension, is supported by the multiple regression analysis but not by the correlation coefficients. The correlation coefficient shows an association between initial stiffness and final extension at the p = 0.01 level. The greater the initial stiffness, the greater the initial contracture and contracture time. The conflict in statistical results may be again due to the small sample size, or to other unidentified variables such as tissue pathology. Clinically, considering the histologic process of maturing fibrous tissue, one would expect that a very stiff, long-standing contracture would not resolve as well as one that was not as stiff for as long.

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warrant further investigation so that these associations can be confirmed or rejected.

This study indicated that the greater the initial extension deficit, the less the flexion contracture resolved. If this is the case, further investigation into this relationship and what it implies clinically is necessary. The rate of improvement as a clinical indicator of outcome is a very interesting notion. This study showed that, for flexion contractures between 25 and 65°, on average more than 50% improvement can be expected in the first 2 weeks of splinting. If rate of improvement can be used as a predictor of final average outcome, treatment expectations and indications for surgical release may alter.

Another interesting clinical question has been raised in the course of the study: Is TERT (splint wear time and splinting duration) the most important factor in resolving a flexion contracture? If it is, then further research is necessary to ascertain the most clinically effective splint-wearing time and splinting duration. This study suggests that splinting duration needs to be continued for at least 4 months on average. The question of compliance is also important. If TERT is directly related to compliance, perhaps the patient should be more involved in making the splint choice. The effect of compliance on TERT also needs to be evaluated.

Callahan and McEntee7 and Colditz2 report from clinical experience that springy and non-springy joints respond differently. These authors suggest that the joint springiness should be considered when choosing the type of splint to be used in treatment. Data from this study do not support this. The criteria for choosing a splint may require re-evaluation. Further research is necessary to determine if there is an association between joint springiness (torque curve) and response to splinting. This study would also suggest that caution is required in interpreting and adhering to clinical principles that have not been scientifically investigated. Many of these exist in the area of splinting. This study is a start on scientific investigation in this area. It identifies many of the difficulties of clinical research on such issues but also identifies the urgency for knowledge based on research rather than clinical inference.

CONCLUSION

The question of appropriate and effective splinting of the PIP joint interests all therapists dealing with this difficult problem. This small clinical study showed that the average resolution for PIP joint flexion contractures between 25 and 65° was 21°. Statistically, there was an association between splintage and final extension deficit. The longer the splinting duration, the lower the final extension deficit. This implies that TERT is one of the major factors in resolving PIP flexion contracture.

Statistical analysis also confirmed positive associations between contracture time, stiffness, and final outcome; that is, the longer the contracture was present, the greater the final extension deficit. Furthermore, the greater the initial stiffness, the longer the splinting time and the greater the final extension deficit. Splinting time in terms of splinting duration was the most significant factor in the resolution of the flexion contracture.

The association of stiffness before and after treatment was supported. The joints that were stiffer before splintage remained the stiffer joints after splintage. The stiffer joints did, however, make some improvement in passive extension.

A dynamic splint applied with a torque of 0.24 Nm is effective in resolving a flexion contracture from 39 to 21° on average. There is a sound premise for the clinical application of a dynamic splint for treating PIP flexion contracture, regardless of the severity of the contracture, the time of contracture, or the stiffness of the joint, provided adequate TERT is maintained.

REFERENCES