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Comparison of Range-of-Motion Constraints Provided by Splints Used in the Treatment of Cubital Tunnel Syndrome—A Pilot Study

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ABSTRACT: Nocturnal splinting of the elbow is commonly used to treat cubital tunnel syndrome (CBTS). Rationales are based on several studies, which suggest that proper nocturnal positioning of the elbow during sleep contributes to decreased cubital tunnel symptoms. Currently there is limited scientific evidence supporting the rationale for specific splinting protocols. Splints may be custom or prefabricated. The purpose of this article is to assess the range-of-motion constraints of five nighttime elbow orthoses commonly used in the treatment of CBTS. This preliminary study was conducted using a cadaveric model, using three arms to represent three human arm sizes, and compared five different splints, and no splint. Range-of-motion testing was performed using gravity alone and then testing was repeated using gravity plus a 1-pound weight in a standardized fashion. Results showed that all splints restricted elbow flexion significantly more than the unsplinted extremity. Of the five splints, the AliMed splint allowed the most elbow flexion both in the gravity assisted, and gravity plus a 1-pound weight assisted conditions. The only splint that restricted elbow extension was the Hely & Weber splint. The Pil-O-Splint Elbow Support with stay, Hely & Weber and the Folded Towel all restricted elbow flexion to less than 90° under all study conditions. The information provided may be helpful in making clinical decisions regarding splinting for CBTS.

J HAND THER. 2006;19:384–92.

Cubital tunnel syndrome (CBTS) is the second most common peripheral compression neuropathy.[1] It occurs when a combination of factors, which are still not well understood, produce ischemia of, and damage to the ulnar nerve. The symptoms of CBTS may consist of sensory and/or motor dysfunction. Pain quality can be sharp or aching in nature and can be located primarily on the medial side of the proximal forearm, or can be diffuse and radiate proximally and distally in the arm. Paresthesias, dysesthesias, decreased sensation, a feeling of coldness, muscle weakness, and atrophy may be present along the ulnar nerve distribution.[2]

In recent years, there has been limited discussion and research regarding the best conservative techniques for the treatment of CBTS, and debate continues within the literature. Rationales for overnight elbow splinting are based on several studies, which suggest that passively and actively sustained positions of the wrist, elbow, and shoulder assumed during nighttime positioning, can contribute to elevated cubital tunnel pressures and strain on the ulnar nerve.[1–4] Although many causes and treatments have been described, nocturnal splinting of the elbow to restrict the elbow from acute elbow flexion remains a standard component of nonsurgical intervention. There are many splints available, commercial and custom made, and almost as many factors to consider when prescribing a particular product or immobilization technique. Some authors have suggested that restricting elbow flexion to between 30° and 90° is helpful in managing CBTS.[2–6] However, the basis of these recommendations remains questionable. When prescribing and fitting any orthotic device, it is important to understand its performance

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doi:10.1197/j.jht.2006.07.028

characteristics and properties. The primary purpose of this study is to evaluate the abilities of five such splints for their effectiveness in restricting elbow flexion.

For research purposes, our null hypothesis was that the five splints evaluated would perform equally well to restrict elbow range of motion (ROM).

MATERIALS

Three cadaver arms were selected to represent three human arm sizes: small, small/medium, and medium. Gender, size, and best cadaver choice were determined by the availability of cadaveric extremities. The arms were harvested to include the scapula, shoulder, elbow, wrist, and fingers. Size criteria were based on a synthesis of commercial splint manufacturer recommendations, and best overall splint fit based on therapist clinical judgment. The criteria for size for each anatomical location were determined by circumferential measurements as presented below in inches:

	Foreman	*Biceps*
Small	≤9	≤11
Medium	9–10.5	11.5–13

The sizes of the extremities accepted for inclusion in the study were measured in inches and were as follows:

	Forearm	*Biceps*
Small	6.25	6.50
Small/medium	8.75	11.00
Medium	9.50	11.50

All the cadaver arms had normal ROM except for the small cadaver arm, which had an elbow flexion contracture of 15°. We included the only small arm available for harvest despite the 15° contracture, because the contracture was determined to be irrelevant to the outcome of the study because our primary focus was the amount of elbow flexion each splint would restrict.

A 16-inch extremity positioning jig was fabricated from Polyform and made to fit over a wooden dowel measuring $2 \times 4 \times 37$ inches. The jig flared out at the bottom into a 2½-inch-deep shelf upon which each cadaver scapula was supported. The purpose of this apparatus was to ensure consistent positioning of the subjects. The jig was attached with large strips of 2-inch-wide sticky back hook and loop Velcro to the underlying wooden dowel. The upper arms were supported by 2-inch Velfoam strips attached by Velcro as close to the elbow as possible without interfering with free flexion. The wooden block, in turn, was attached with a clamp to a rigid vertical post. Forearm rotation was not restricted by the jig (Figure 1).

FIGURE 1. *Extremity testing of jig.*

Five splints and methods for restricting elbow flexion were evaluated and compared to a non-splinted elbow. The five splints evaluated in this study were (Figure 2)

- A large bath towel, applied circumferentially around the elbow joint as shown in Figure 3.
- IMAK Corp. Pil-O-Splint Elbow Support, adjustable with rigid plastic stay.
- IMAK Corp. Pil-O-Splint Elbow Support, adjustable with rigid plastic stay removed.
- Hely & Weber Cubital Tunnel Splint (Prototype) (Body Glove Corp., CA).
- AliMed Cubital Tunnel Syndrome Support.

Splints were chosen for inclusion in the study because they represented a wide spectrum of splint styles and immobilization designs. Descriptions of these are listed below. The Pil-O-Splint Elbow Support was measured with the rigid plastic stay inserted and then repeated with the stay removed. This splint alteration was also evaluated because patients are routinely advised of the option to remove the stay if they find the splint too rigid or uncomfortable. This option is offered at this treatment facility with the aim of improving compliance with nightwear.

The only "custom splint" evaluated was a large bath towel fastened circumferentially around the

AliMed Cubital Tunnel Syndrome Support	Made with soft, beige tricot laminated to polyethylene foam, with firm, but nonrigid bilateral foam inserts (Figure 4).
Hely & Weber Cubital Tunnel Splint (Prototype)	Made with neoprene, stockinette, Velcro and plastic. It is a lined, semirigid dorsal elbow support molded into approx 15° of flexion with three volar straps (Figure 5).
Pil-O-Splint With Stay	Made with breathable foam covered with soft fabric for cushioned support with a removable plastic stay (Figure 6).
Pil-O-Splint Without Stay	Same as above, with rigid longitudinal plastic stay removed (Figure 7).
Custom Circumferential Towel Support	Trifolded 48 × 30 inches bath towel, circumferentially wrapped and fastened with duct tape (Figure 8).

elbow, and secured with duct tape. Sailer[3] describes such a splint: ''A small pillow or folded towel can be secured into the antecubital fossa to effectively limit flexion greater than 45°.'' The towel that we studied was moderately thick and soft. It was 48 × 30 inches, folded three times lengthwise to a width of 10 inches, wrapped circumferentially around a medium arm and fastened with duct tape (Figure 3). Once donned, its thickness was 4 inches. It was noted that although the procedure of wrapping and taping was somewhat time consuming, once the splint was formed for the individual, it could be donned and doffed easily.

METHODS

Each cadaver arm was placed in a clear long plastic shower glove to contain blood, protect the splints, and preserve the cadaver prior to testing. The plastic glove did not restrict ROM. A Futuro Wrist Splint was placed on each cadaver wrist to stabilize and

FIGURE 2. Splints evaluated in this study.

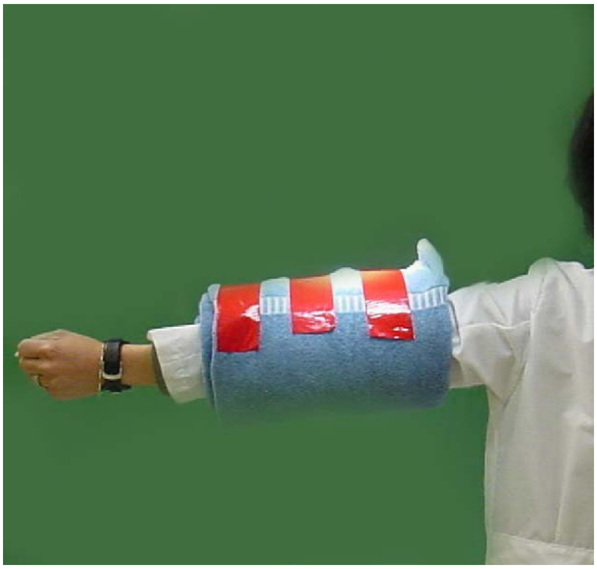

FIGURE 3. Custom circumferential towel support.

standardize wrist positioning during elbow ROM testing. Two experienced hand therapists performed ROM testing.

Testing of gravity only assisted elbow extension was obtained. The cadaver arm was allowed to lie on a table in a gravity-assisted position of complete extension, with the disarticulated proximal arm supported by a helper in a standardized fashion. A goniometric measurement of elbow extension was taken. This was then repeated with a 1-pound weight overlying the wrist.

The cadaver arm was fastened to a vertical Polyform jig with the scapula supported on a 2½-inch-deep shelf with the upper arm supported by 2-inch Velfoam strips. The forearm was allowed to hang freely in flexion to simulate gravity only assisted flexion of the elbow. This was then repeated with a 1-pound weight overlying the wrist.

Goniometric testing protocol deviated from American Society of Hand Therapists recommended technique by consistently lining up the long arms of the goniometer parallel to the medial aspect of the humerus and the ulna instead of the lateral side, to obtain both elbow flexion and extension measurements.[9] This approach was used because the disarticulated arm could most reliably be measured from this side. A conventional 12-inch, 360°, plastic goniometer with two rigid arms, was used (Figure 1).

Prior to collection of study data, assessment reliability was established by paired measurements in 12 practice ROM trials. The first examiner placed the goniometer. The second examiner located 2 feet away, confirmed proper goniometric placement and also photographed the process. This was repeated with the two examiners trading roles. The data obtained by the examiners for the preliminary test subject were compared. Differences between paired goniometric observations never exceeded 5° and were deemed to be sufficiently reliable and repeatable.

One therapist measured the ROM while the second examiner was 2 feet away, confirming the goniometer placement and photographing the process. A third therapist was always required when measuring elbow extension to stabilize the extremity. After initial ROM testing without an elbow splint, each of the five elbow orthoses was donned in sequence. ROM elbow extension and flexion measurements were taken with each splint, with and then without a 1-pound weight. The technique described above was then repeated for all three cadaver subjects. All goniometric measurements were rounded to the nearest 5° during study testing (Figures 4–8).

RESULTS

ROM measurements are reported in Table 1 as extension/flexion. The elbow flexion contracture of the small left arm appears as a positive number for statistical purposes. It should be noted that the extension measurements do not reflect any movement past neutral. All positive extension numbers indicate degrees of restriction (Table 1).

RESULTS

The AliMed splint allowed the most elbow flexion with an average 110° flexion without the weight and 120° flexion with weight. The Hely & Weber splint allowed the least flexion (averaging 53° without weight and 68° with weight). All of the tested splints allowed full extension except the Hely & Weber, which restricted full extension, averaging 17° without

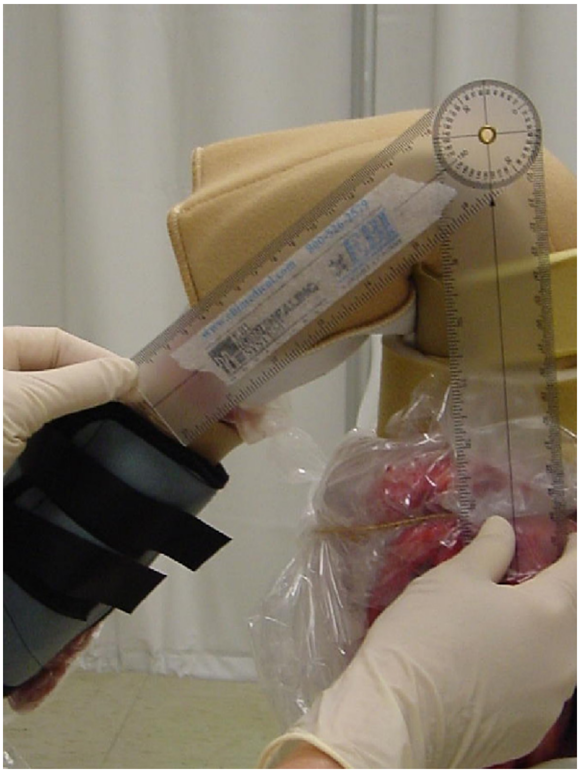

FIGURE 4. *AliMed Cubital Tunnel Syndrome Support.*

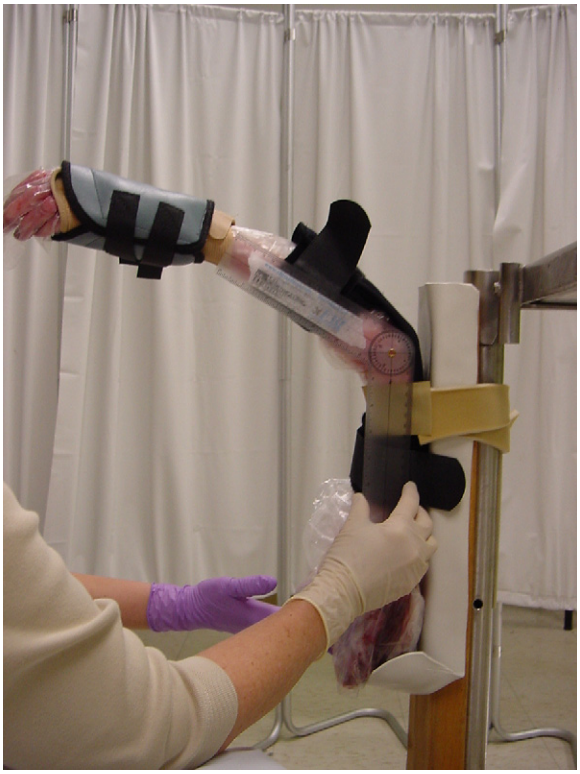

FIGURE 5. *Hely & Weber Cubital Tunnel Splint.*

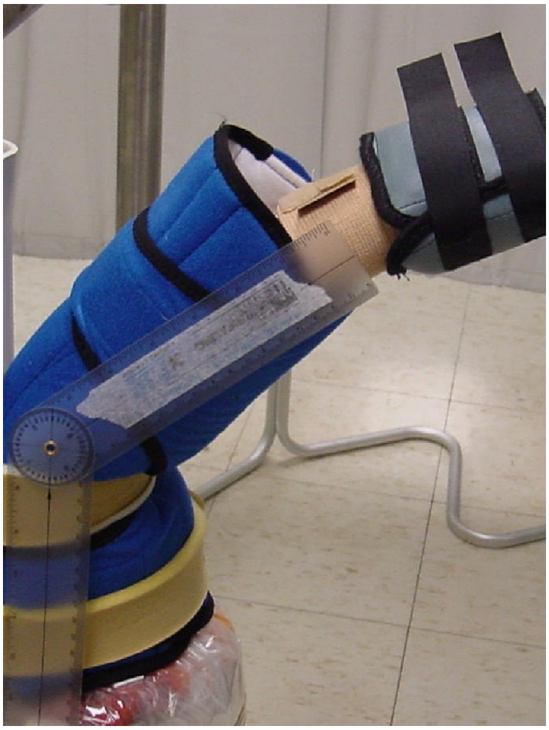

FIGURE 6. *Pil-O-Splint with stay.*

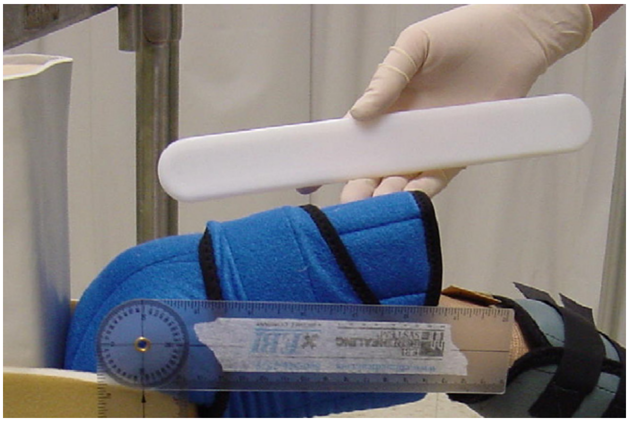

FIGURE 7. *Pil-O-Splint without stay.*

weight and 15° with the 1-pound weight. The Pil-O-Splint Elbow Support with stay, Hely & Weber splint, and the Folded Towel, all restricted elbow flexion to less than the 90° criteria, both with and without weight applied. These same splints were also the only ones to meet a flexion criterion of less than 100−110° (Figure 9).

Inferential Analysis

The null hypothesis was that there would be no difference in the splints' ability to restrict ROM under the specific laboratory conditions. Analysis of variance (ANOVA) and Tukey post hoc tests were used to evaluate the differences among splints both with and without weights. Both flexion ANOVAs were significant ($p = 0.001$), while differences were not significant for extension.

DISCUSSION

All of the splints failed a 40−50° range criteria for the lowest mean extraneural and intraneural pressures described by Gelberman et al.[6] Because all the splints evaluated in this study also failed the 30−70° range criteria defined as being significantly lower than full extension, a different criteria statement was considered. Gelberman et al. also described greater than 100−110° as the point at which the most significant pressure increases occurred.

Several studies investigated elevated cubital tunnel pressure as a factor in the development of CBTS. Increased traction on the ulnar nerve is also cited as a significant contributor to ulnar nerve compromise. Studies show that increasing pressure and traction develop with positions of increasing elbow flexion.[1,5,6,8,10,11] Bozentka[1] noted that, "As the elbow is brought into full flexion there is a 55% decrease in canal volume." Manicol examined extraneural pressures affecting the ulnar nerve at the elbow in various degrees of flexion using cannulae connected

TABLE 1. **Range-of-motion Measurements**

	Without Weight	*With Weight*
Small Arm		
No splint	15/160	15/160
AliMed	15/125	15/135
Hely-Webber	15/50	15/60
Pil-O-Splint with stays	15/70	15/100
Pil-O-Splint without stays	15/110	15/120
Folded towel	15/80	15/90
Small-Medium Arm		
No splint	0/150	0/150
AliMed	0/115	0/125
Hely-Webber	20/65	10/75
Pil-O-Splint with stays	0/80	0/105
Pil-O-Splint without stays	0/100	0/115
Folded towel	0/55	0/70
Medium Arm		
No splint	0/135	0/145
AliMed	0/90	0/100
Hely-Webber	15/45	15/70
Pil-O-Splint with stays	0/35	0/50
Pil-O-Splint without stays	0/65	0/90
Folded towel	0/35	0/60

FIGURE 8. *"Homemade" folded towel support.*

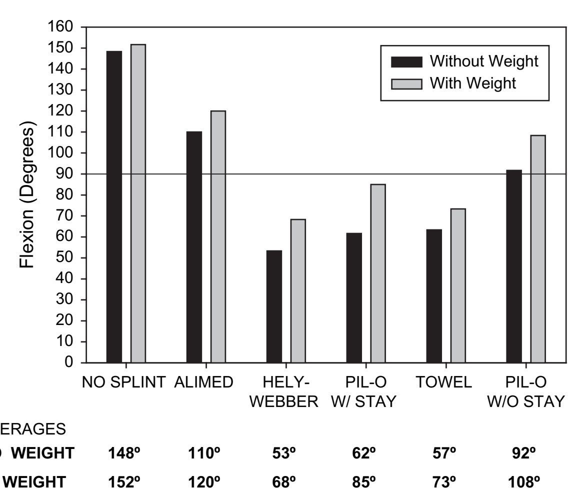

FIGURE 9. *Statistical analysis.*

to a pressure transducer using a closed, oil filled system. Pressure measurements were obtained from ten fresh cadaveric arms with the shoulders in 0°, 90°, and 135° of abduction. He took pressure readings of the ulnar nerve at the cubital tunnel, the postcondylar groove and the medial intermuscular septum. He found that, ''Significant pressure increases occurred when the elbow was flexed beyond a right angle, and concomitant shoulder abduction further raised the pressures recorded at the cubital tunnel and postcondylar groove.'' ''Further flexion of the elbow (150° with the shoulder at 90°) produced highly significant rises in pressure at all three sites and almost doubled pressures recorded in the groove and at the septum when the shoulder was not abducted.''[10]

Penchan and Julis measured intraneural pressure of the ulnar nerve in cadavers. Their objective was, ''To analyze the two most conspicuous mechanisms of ulnar nerve damage, i.e., the stretch of the nerve and its compression by the aponeurosis of the flexor carpi ulnaris.'' They found that, ''In elbow extension, the tissue pressure in the ulnar nerve in the cubital tunnel was found to be about 7 mm Hg. In elbow flexion at a right angle, this pressure rose on an average to 11–24 mm Hg, according to the position of the wrist and shoulder. In the position of the ulnar nerve maneuver [full elbow flexion], pressure averaging 46 mm Hg was found in the ulnar nerve. This intraneural hypertension is apt to disturb capillary circulation and to directly damage nerve fibers of the ulnar nerve.''[5]

Gelberman et al. used magnetic resonance imaging and pressure catheters to determine compression and strain on the ulnar nerve along with visualization of the cubital tunnel with increasing elbow flexion in 10° increments from 0° to 130° of flexion. They concluded that, ''The lowest mean intraneural pressure was recorded with the elbow flexed 50°, and the lowest mean extraneural pressure was recorded with the elbow flexed 40°.'' He also found that the greatest amount of pressure was seen with the elbow at 130° of elbow flexion. He concluded that, ''The cubital tunnel is a dynamic region morphologically. Both the cubital tunnel and the ulnar nerve change in the area by as much as 50% as the normal elbow is flexed and extended, with substantial flattening of the ulnar nerve but no evidence of direct, focal compression. These morphological findings corresponded well with measurements of interstitial pressure, which demonstrated an initial increase in intraneural pressure without a corresponding increase in extraneural pressure. This indicates that traction on the ulnar nerve is a major cause of increased intraneural pressure in association with flexion of the elbow.'' ''As neural traction appears to be a source of increased intraneural pressure under normal conditions, it appears reasonable that a goal of treatment of entrapment neuropathy is the elimination of all sources of nerve impingement, including those causing excessive neural traction.''[6]

Wright et al.[8] used ten cadaveric arms to measure excursion of the ulnar nerve with various upper-extremity positions. He found that, ''Elbow flexion (of 90°) is responsible for an average strain (increase in tension) of 29%, well above the 15% strain reported to be deleterious to the nerve by Ogata and Naito.'' Ogata and Naito had applied various degrees of stretch to the sciatic nerves of rabbits. The average stretching of more than 15.7% caused complete arrest of blood flow in the stretched nerve. The average stretching force at this point was 74 g. Complete standstill of intraneural circulation was observed under compression of 50–70 mm Hg.[12] Byl et al.[11] also examined strain on the median and ulnar nerves and found that, ''A statistically significant increase in ulnar nerve strain occurred with elbow flexion.''

Other investigators focused on the consequences of sustained pressure or strain on nerves as it relates to edema, ischemia, and ability to recover. Rempel et al. reviewed literature in which the physiological, pathophysiological, biochemical, and histological effects of biomechanical loading on the peripheral nerves were evaluated in humans and animals. Their review of the literature concluded: ''On the basis of the animal studies, it appears that if elevated extraneural pressures are maintained for an adequate duration the initial injury, remodeling, and repair mechanisms, which are constantly ongoing, may be overwhelmed, leading to persistent extraneural or intraneural edema and eventually to synovial or intraneural fibrosis and loss of nerve function.''[13]

Clark et al. studied the sciatic nerves of rats and the effect of tension upon nerve blood flow. They found that, ''Nerve blood flow decreased approximately 50% with substantial recovery in 30 minutes after 8% elongation, whereas 15% elongation produced approximately an 80% reduction in blood flow with minimal recovery.''[14] Wall et al. exposed the tibial nerves of 24 rabbits, and the nerves were stretched by 0%, 6%, and 12%. At 6% strain, the amplitude of the action potential had decreased by 70% at one hour and returned to normal during the recovery period. At 12% strain, conduction was completely blocked by one hour and showed minimal recovery.[15]

Hong et al. compared 12 ulnar nerves in ten patients, assigning them randomly into two groups. Group A was treated with splinting only. Those patients were advised to use a splint limiting elbow flexion to 30–35° the whole night during sleep and on any other occasion that warranted flexion of the elbow during which the ulnar nerve might be compressed at the elbow. Group B was treated with local steroidal injections in addition to splinting. They were assessed one and six months after treatment. This study concludes that, ''Splint application alone is adequate to improve the symptoms and ulnar nerve conduction across the elbow. The addition of a steroid injection did not provide further benefit in the treatment of cubital tunnel syndrome.''[4]

There are many custom fabricated, commercial, and ''homemade'' splints, of many variations available for the treatment of CBTS. Clinically, we postulate that some cubital tunnel splints may be superior to others in achieving the desired restriction of elbow flexion, especially in the sustained positions that usually occur during sleep.

Review of research literature reveals that optimal positioning of the elbow during sleep is still not well understood. There are many discrepancies between authors' recommendations. There was a range of elbow flexion from between 30° to 35°, according to Hong et al.,[4] and 45° was recommended by Bozentka,[1] Gelberman et al.,[6] and Sailer.[3] Blackmore noted ''Most patients do not tolerate full elbow extension splinting, so a position of 30° to 60° is suggested.''[2] Gelberman et al.[6] also reported that with elbow positioning in full extension, the mean intraneural and extraneural pressures within the cubital tunnel were higher than they were with the elbow at 30–70° of flexion. According to our data, none of the splints held the elbow within the 30–45° or 30–70° ranges cited above. The Pil-O-Splint Elbow Support with stay, Hely & Weber splint, and the Folded Towel, all restricted elbow flexion to less than a 90° range criteria both with and without weight applied. The same splints were the only ones to achieve a less than 100–110° ROM restriction criteria.

The fetal position is a common sleeping position. When full elbow flexion is combined with shoulder abduction, strain on the ulnar nerve increases significantly. Despite evidence that shoulder abduction may exacerbate ulnar neuropathy,[8,10,11] especially when combined with elbow flexion, nocturnal splinting is typically limited to the elbow. The logistics of controlling shoulder abduction during sleep are challenging. It must suffice to educate the patient and hope that he or she will attempt to voluntarily change or modify sleep positions. Wrist extension, pronation, and radial deviation also affect the ulnar nerve.[8,11] Most authors do not address wrist positioning for ulnar neuropathy. The positioning of the shoulder and/or wrist and fingers, and their effect on ulnar nerve pressure or traction may be the subject of future studies.

It is important to note that there are many variables that should be considered in splint design and selection in addition to ROM parameters. Some of these include comfort, dermatological issues (due to skin contact with different materials), elevated cubital tunnel pressure secondary to pressure exerted by the splint itself, skin temperature generated by splint material, practicality (including ease of splint application and splint maintenance), cosmesis, durability, functionality, and many other factors, which may affect patient compliance.[7]

Study Limitations

An important limitation of this study is that the subjects were cadavers instead of living human subjects. It is unknown to what extent the difference in resting tension of cadaver versus living tissues, as well as the effects of repeated ROM, may have affected the outcome of this study. Another limitation was the small number of cadaver arms used. The number and size of cadavers was limited by availability. As noted above, the small cadaver had a 15° elbow flexion contracture. The authors opted to include the small arm as the elbow contracture was determined to be irrelevant to the outcome of the study because our primary concern was the amount of elbow flexion each splint would restrict, and that parameter was unaffected.

The use of cadavers eliminates any evaluation of splint comfort, compliance, pressure, and temperature generation. As previously mentioned, various neck, shoulder, elbow, and hand postures are assumed and maintained during sleep that may influence the ulnar nerve. This study focused only on the elbow. Only a limited number of splints were evaluated in this pilot study. Future areas suggested for research would be studies involving living human subjects, assessment of different postures, including variations of shoulder, elbow, wrist, and digit positioning in combination and individually. Customized and prefabricated cubital tunnel splints should also be studied.

CONCLUSION

In comparing the ROM constraints of five different types of nighttime splints used in the conservative treatment of CBTS, the AliMed splint allowed the most elbow flexion with an average 110° without the weight and 120° with weight. The Hely & Weber splint allowed the least flexion (averaging 53° without weight and 68° with weight). All of the tested splints allowed full extension except the Hely & Weber, which restricted full extension averaging 17° without weight and 15° with the 1-pound weight. The Pil-O-Splint with stay, Hely & Weber splint, and the Folded Towel were all effective in preventing elbow flexion beyond the 100–110° criteria cited as being most significant for increasing cubital tunnel pressure. There is limited scientific evidence regarding optimal splinting protocols for CBTS; therefore, additional research in this area is recommended.

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Quiz: Article #040

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#1. The purpose of the study was to assess
  a. the cubital tunnel pressures while wearing five different elbow splints.
  b. the effectiveness in treating CBTS with five different elbow splints.
  c. the ROM constraints of five different elbow splints.
  d. the role of five different ROM settings on CBTS.

#2. CBTS is
  a. the second most common peripheral compression neuropathy in the upper extremity.
  b. the second most common peripheral compression neuropathy affecting the ulnar nerve.
  c. the most common compression neuropathy in the upper extremity.
  d. as common as carpal tunnel syndrome

#3. The null hypothesis was
  a. that the custom made splint would be the most effective in restricting elbow flexion.
  b. that the Hely & Weber splint would be the most effective in restricting elbow flexion.
  c. that the AliMed splint would be the least effective in restricting elbow flexion.
  d. that the five splints would restrict elbow ROM equally.

#4. The only custom splint evaluated was
  a. a posterior plaster shell flexed at about 30°.
  b. a thermoplastic bivalve flexed at about 45°.
  c. a large towel circumferentially applied and taped about the elbow.
  d. an anterior block splint with a 40° flexion stay.

#5. The____________splint allowed the least elbow flexion.
  a. AliMed
  b. Hely & Weber
  c. Folded Towel
  d. Pil-O-Splint

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