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Comparative strength of elbow splint designs: a new splint design as a stronger alternative to posterior splints

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Background: Musculoskeletal injuries of the upper extremity are frequently treated with temporary external immobilization. Traditionally, long arm posterior splints have been used to limit flexion/extension of the elbow. However, long arm posterior splints have been observed to fail clinically, necessitating a stronger alternative. In this study, we assessed the biomechanical strength of the long arm posterior splint compared with a new spiral splint design.

Methods: One male and one female participant were placed 10 times in long arm posterior splints and 10 times in spiral splints. Both splint types were subjected to a downward mechanical load of 39.2 N (4 kg) and assessed for a change in both flexion/extension and pronation/supination.

Results: There was no significant difference in starting position or starting flexion/extension between the 2 splint designs. Posterior splints allowed significantly greater initial pronation/supination compared with spiral splints. Both splint groups had significant increases in flexion/extension and pronation/supination compared with their starting ranges of motion. There was no significant difference in the change in pronation/supination between the 2 splint groups. Finally, posterior splints allowed a significantly greater change in flexion/extension compared with spiral splints.

Conclusion: Spiral splints offered less initial pronation/supination than long arm posterior splints. Furthermore, spiral splints are able to resist flexion/extension of the elbow after application of a downward mechanical load better than posterior splints, thus suggesting spiral splints are mechanically superior to long arm posterior splints.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Spiral splint; posterior splint; elbow; forearm; immobilization; biomechanics

Musculoskeletal injuries account for 77% (65.8 million) of all health care visits in the United States (US), with most (35.4 million) occurring as fractures and sprains.[16] In 2010, elbow and forearm injuries made up 15% of all sprains and strains treated in physician offices.[16] Furthermore, in the US the incidence of upper extremity fractures is 67.6 per 10,000 persons annually; thus, it is important to evaluate the most effective treatment options available for such injuries.[9]

The Mount Sinai Institutional Review Board approved this study (approval numbers: HS #16-00906 and GCO #1601629(0001)).

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External immobilization techniques, such as casts or splints, are common treatment methods for less severe injuries of the wrist, elbow, and forearm and are used for postoperative and fracture stabilization during recovery.[1,6,10,17]

Although there are many techniques for immobilization of forearm injuries, they differ in their design and safety. Due to the heat production during the exothermic reaction required for plaster to set, skin burns and breakdown are common complications, requiring care to be taken to minimize this risk.[3,5,7,8] Gil et al[3] demonstrated a modified sugar tong splint to avoid skin breakdown at the posterior elbow; however, a sugar tong splint is not appropriate when attempting to reduce flexion and extension about the elbow. Recently, Manocha et al[13] reported the failure of hinged elbow orthosis to stabilize the elbow after lateral collateral ligament injury, suggesting the necessity of more stable immobilization methods about the elbow. In terms of immobilization, the inability to maintain alignment and reduction across a fracture can lead to poor patient outcomes.[4,12]

Although there is a paucity of literature describing the variation in ability to maintain alignment and reduction across splinting types, it is reasonable to deduce that an unstable reduction may result from a lack of immobilization. Furthermore, immobilization promotes soft tissue healing. As such, posterior incisions with underlying hardware or skin grafts require careful immobilization.

Beyond safety and concern for skin irritation, the most important factor of temporary immobilization is the strength of the splint applied in resisting the desired vector of motion (ie, flexion/extension or pronation/supination). When fractures of the forearm and elbow are immobilized, the standard of care is currently a long arm posterior splint.[2] Clinically, the senior author (M.R.H.) has observed that long arm posterior splints are relatively weak and often fail shortly after application, especially with patient noncompliance to restriction of movement. We have not, however, encountered data investigating failure rates at this time.

In our practice, we use a new "spiral splint" to stabilize the elbow. Clinically, we believe this immobilization technique is stronger by resisting motion in the flexion/extension axis and safer by avoiding pressure points and, therefore, thermal burns about the elbow under the splinting plaster. The goal of this study was to assess the strength of the spiral splint compared with a traditional long arm posterior splint.

Materials and methods

This mechanical study assessed the differences between a new spiral splint design and a traditional posterior splint design in their ability to resist failure about the elbow when exposed to a load.

Splint application and testing

Posterior splints and spiral splints were tested. Before splint application, upper limbs were wrapped with a protective layer of cotton webbing to prevent skin irritation and thermal burns. All splints were applied with the standard 10 layers of plaster. With the elbow at 90° of flexion, fingers extended, and the wrist in a neutral pronation/supination position, posterior splints were applied by starting at the metacarpal phalangeal joint and continuing along the posterior aspect of the forearm, over the olecranon, and up the posterior portion of the humerus, terminating at the level of the base of the deltoid (Fig. 1).

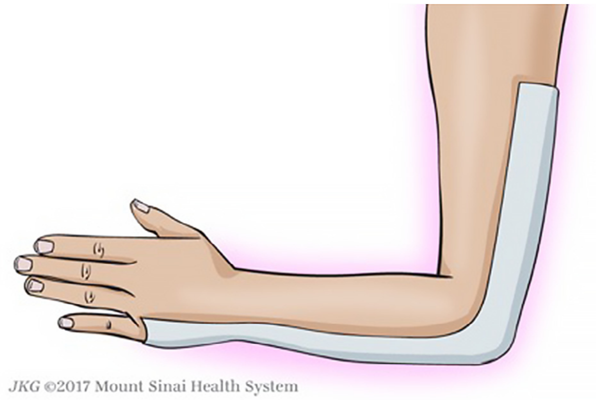

Figure 1 Drawing of the placement of the plaster in the posterior splint. With the elbow at 90° and the wrist in a neutral position, the posterior splint is fashioned from the metacarpal phalangeal joint along the posterior aspect of the forearm and humerus, terminating at the level of the deltoid.

Spiral splints were fashioned by first creating a triangular fold in the palm. Again, with the elbow at 90° of flexion, fingers extended, and the wrist in a neutral pronation/supination position, the spiral splint wraps from the volar aspect of the hand around the dorsal side of the hand, continuing at an angle along the forearm, crossing over the lateral epicondyle, then continuing to wrap around to the medial side of the humerus and ending at the level of the deltoid (Fig. 2).

The male and female participants volunteered to undergo several rounds of splinting. One orthopedic senior resident applied all splints. To control for arm size and strength, 1 female and 1 male participant were used in this study and each splint was applied to each arm (right and left) multiple times. A 4-inch plaster (BSN Medical Inc., Rutherford College, NC, USA) was used for the female participant, and a 6-inch plaster (BSN Medical Inc.) was used for the male participant.

Preliminary data demonstrated an 11° difference in the flexion/extension axis between the 2 splint types in a trial run of force application. A power analysis was conducted using this value and determined 5 splints in each group were needed to detect an 11° difference via an independent *t* test with 80% power and an α of 0.05.

Left and right arms were each splinted 5 times with a posterior and spiral splint, respectively, resulting in 2 groups with 10 trials each. Plaster was activated using water between 32°C and 34°C, and splints were allowed to set for 60 minutes before testing. After 60 minutes, and before testing, a starting position of 90° of elbow flexion was confirmed, and range of motion about the elbow (flexion/extension) and the wrist (pronation/supination) was measured using a goniometer. Using a tensile force sensor (IDO Isometer; Innovative Design Orthopaedics, Berkshire, UK) anchored to the ceiling

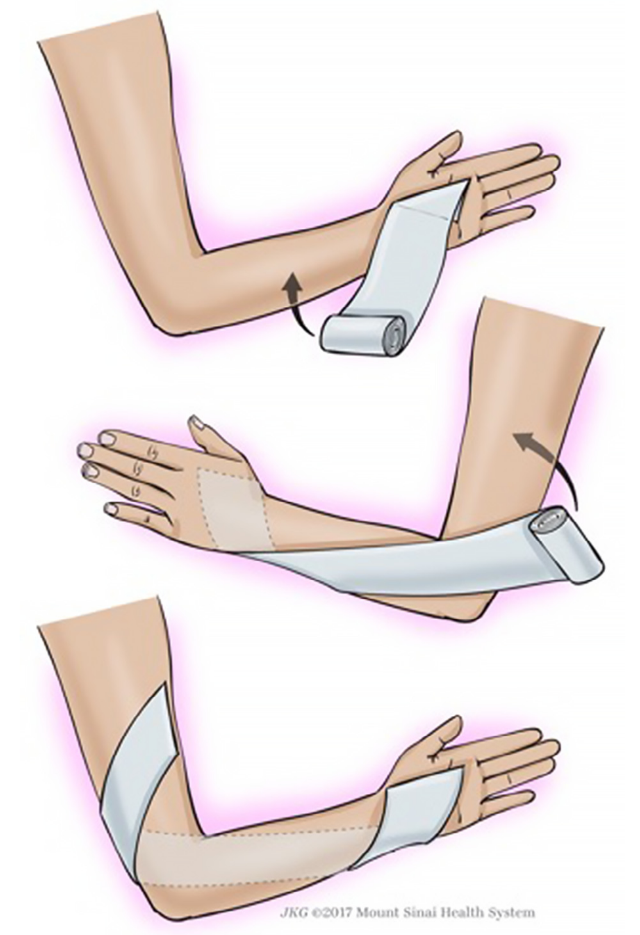

Figure 2 Drawing of the application of a spiral splint. With the elbow at 90° and the wrist in a neutral position, the spiral splint starts at the volar aspect of the palm and continues to wrap around the wrist dorsally. The olecranon is left exposed as the plaster wraps around the lateral epicondyle, terminating on the medial side of the mid-humerus.

with the other end attached to a resistance band of constant resistance, participants pulled down by extension of the elbow with 39.2 N (4 kg) of force and held this load for 5 seconds (Fig. 3). This force value was chosen based on the highest amount of force that both participants could generate and sustain for an extend period of time. Range of motion was again measured as flexion/extension and pronation/supination to assess for failure of the splints.

Data analysis

Data for the posterior and spiral splint groups were analyzed in aggregate. Normality of the data was confirmed via Shapiro-Wilk tests (posterior, $P = .629$; spiral, $P = .091$). Descriptive statistics were then performed. Mean motion differences in flexion/extension and pronation/supination were assessed before and after force was applied by independent t tests to determine whether statistically significant differences exist between the 2 splint groups at these 2 time points. A paired t test was also performed to assess whether, on average, individual splints increased in their total range of motion in flexion/extension and pronation/supination after the application of force.

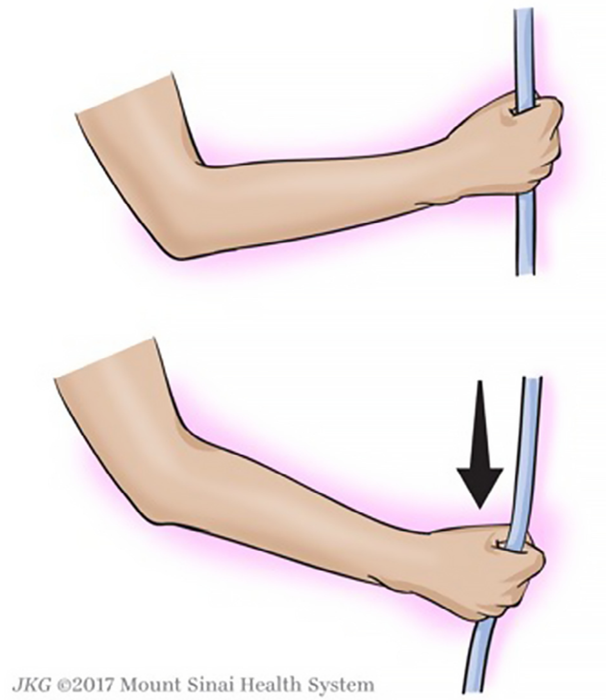

Figure 3 A 39.2 N force was applied to each splint by pulling on a fixed tension band attached to a tensiometer anchored to the ceiling.

Results

Descriptive data of the starting positions and ranges of motion of the 2 splint groups are reported in Table I, and the full data sets for all trials are provided in Table II. There was no significant difference in starting position ($P = .49$) at 90° flexion or flexion/extension range of motion ($P = .10$). However, the posterior splints, on average, allowed significantly more pronation/supination than the spiral splints ($P = .006$). The increase in range of motion for flexion/extension and pronation/supination for both splints was assessed after the application of force (Fig. 4). Both groups had significant increases in flexion/extension and pronation/supination compared with their starting range of motion ($P \leq .001$). When comparing the 2 groups' final range of motion, the posterior splints had significantly increased flexion/extension than the spiral splints ($P < .001$), but there was no difference in pronation/supination between the groups ($P = .20$).

Both groups had significant increases in flexion/extension and pronation/supination compared with their starting range of motion (posterior: 25°, spiral: 10°; $P < .001$). When final ranges of motion in the 2 groups were compared, the posterior splints had significantly increased flexion/extension than

Table I Starting positions and pretest range of motion for posterior splints and spiral splints

Variable	Posterior splint (n = 10) Mean (SEM), °	Spiral splint (n = 10) Mean (SEM), °	*P* value
Elbow flexion	90.5 (2.9)	91.3 (2.1)	.49
Flexion/extension ROM	2.7 (0.7)	1.2 (0.4)	.1
Starting pronation supination	7.6 (1.2)	3.5 (0.4)	.006

SEM, standard error of the mean; *ROM*, range of motion.

Table II Full data set indicating all measurements across all trials in the order they were conducted

Trial	Splint type	Splint size	Flexion/extension, °			Pronation/supination, °		
		(inch)	Starting	Final	Difference	Starting	Final	Difference
1	Spiral	4	0	14	14	6	11	5
2	Spiral	4	0	8	8	2	3	1
3	Posterior	4	2	24	22	5	15	10
4	Posterior	4	1	17	16	7	17	10
5	Spiral	6	2	18	16	5	12	7
6	Spiral	6	0	5	5	2	15	13
7	Posterior	6	2	25	23	13	23	10
8	Posterior	6	0	23	23	14	24	10
9	Posterior	4	4	36	32	10	15	5
10	Spiral	4	4	12	8	3	8	5
11	Spiral	6	2	8	6	2	5	3
12	Posterior	6	6	21	15	6	8	2
13	Posterior	4	3	43	40	7	12	5
14	Spiral	4	2	14	12	4	7	3
15	Spiral	6	0	6	6	3	11	8
16	Posterior	6	0	18	18	3	9	6
17	Posterior	4	7	34	27	7	21	14
18	Spiral	4	2	18	16	4	14	10
19	Spiral	6	0	8	8	4	6	2
20	Posterior	6	2	31	29	4	11	7

the spiral splints (posterior: 25°, spiral: 10°; $P < .001$), but the difference in pronation/supination was not significant (posterior: 8°, spiral: 6°; $P = .20$).

Discussion

Although there is a paucity of literature surrounding the relative strength of splint designs, these data demonstrate that not all splints are equal in their stability and strength. Thus, selecting the appropriate splint for the specific type of injury being treated is important. In this study we compared a new spiral splint design with a traditional long arm posterior splint in mechanical strength when subjected to a load.

The spiral splint technique exhibited a significantly smaller increase in flexion/extension after testing compared with the posterior splints, therefore suggesting that spiral splints have stronger mechanical properties, although this was not directly tested. This indicates that spiral splints are superior to posterior splints in their ability to resist

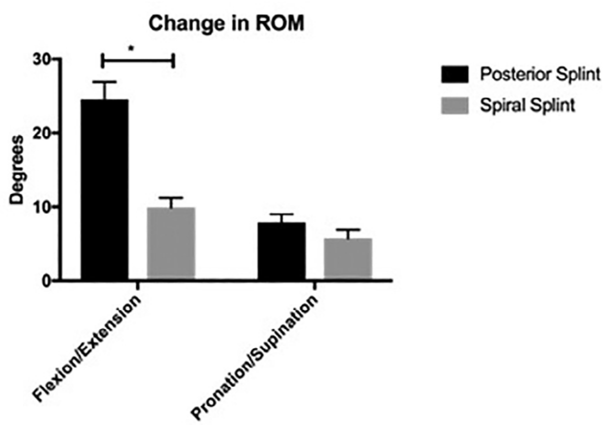

Figure 4 After the application of force, both splints significantly increased the amount of flexion/extension allowed. The increase in flexion/extension was significantly greater in the posterior splint than in the spiral splint. No increases were observed in pronation/supination. Mean data are presented with the standard error of the mean (*error bars*). *$P < .05$.

failure in the flexion extension arc and may therefore provide a more reliable option in stabilizing forearm injuries. Although we have no direct clinical data to show spiral splints lead to better outcomes, these data indicate spiral splints are able to resist failure about the flexion/extension axis and thus can prevent unwanted motion during patient recovery.

Of note, the spiral splint and posterior splint both demonstrated an increase in flexion/extension after application of the load. This suggests the spiral splint may still be subjected to failure, and patients should be instructed to limit use of the injured limb. However, should a patient fail to comply with instructions of limited range of motion, the spiral splint will provide significantly greater stability than the posterior splint and is therefore less likely to fail. The trajectory of the spiral splint does not place the fulcrum of the splint's lever arm directly over the axis of motion in the elbow, thus providing more stability in the flexion extension arc.

Furthermore, posterior splints also allowed significantly more pronation/supination before testing compared with spiral splints. This indicates that spiral splints initially confer more stability in the pronation/supination arc in addition to the flexion/extension arc. There was, however, no significant difference in the change in pronation/supination after the application of load for either splint. This is likely because a torsional load was not also applied; therefore, no failure in the pronation/supination axis was experienced. Despite this, these data suggest the spiral splint also restricts motion about the wrist in addition to failure about the elbow.

Kim et al[11] conducted a study assessing the active pronation/supination allowed by various splint types and found that long arm casts provided greater limitation of pronation/supination than the long arm posterior splint. In addition, posterior splints did not show significant differences compared with short arm casts or any of the other splints tested, thus suggesting posterior splints may not limit pronation/supination as well as may be necessary. Thus, in our study, despite observing no significant difference between the spiral splint and the posterior splint in the change in pronation/supination, the significant difference observed before testing suggests that the spiral splint does in fact limit pronation/supination better than the posterior splint.

Trocchia et al[15] similarly observed that long arm posterior splints do not effectively immobilize the forearm compared with casts. Although we did not investigate a comparison with casts in our study, the significant increase in immobilization and strength observed by the spiral splint indicates that it may be the best option when it comes to immobilization using a splint.

Although not directly tested, we have clinically observed that long arm posterior splints are relatively weak and often fail shortly after application due to their second area moment of inertia in the axis of motion being small. Furthermore, if made sufficiently thick, a posterior splint poses a risk of thermal burns because the heat generated during plaster curing is proportional to its thickness. The spiral splint effectively creates a large second area moment of inertia with minimal plaster thickness, potentially reducing this risk of burns while ensuring a sufficiently stable immobilization technique. Of note, the participants tested did not experience any thermal burns in either splint group.

The study has several limitations, including testing being conducted on only 2 participants. However, we believe that by evaluating 1 male and 1 female participant, we were able to assess both 4- and 6-inch plaster as it would typically be used in clinical practice. Using the same participants over multiple splinting sessions, rather than multiple participants, allowed us to control for arm size, thus ensuring the correct plaster size was used. Despite using the same 2 participants, each splint was applied independently, representing different experimental replicates.

Another limitation of this study was the time each splint was allowed to set. It can take up to 72 hours for plaster to completely set; however, testing this experimentally would have been unreasonable while controlling for confounding variables as well as not a realistic replication of clinical application.[14,18] This was overcome by using a uniform splint set time of 1 hour, the estimated amount of time that typically passes from splint application to patient discharge from the emergency department. The plaster bandage manufacturer states that splints are fully set in minutes, but we felt that a standardized value mimicking the time spent in the emergency department was more appropriate for reproducibility of the study.

Finally, although pretest and post-test supination/pronation was measured, we did not apply a torsional load. We only tested a load in the flexion/extension arc because clinically, this is the mechanism by which we have observed the failure of most splints. Furthermore, posterior splints are typically not used to immobilize a patient in the pronation/supination arc because several other immobilization techniques are better suited for this.

Conclusion

We have demonstrated the superiority of a new spiral splint design to the long arm posterior splint in mechanical strength. We were not able to directly compare the safety of the 2 splints in terms of skin burns and breakdown, but we believe that the spiral splint design allows for more exposed skin around the elbow and wrist, which has the potential to reduce these complications. Most importantly, the increased mechanical strength demonstrated by the spiral splint compared with the posterior splint suggests that its ability to resist a load at the flexion/extension axis and that its reduction in initial pronation/supination make it a better alternative for immobilizing injuries of the forearm and elbow.

Disclaimer

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