Comparison of Forearm Rotation Allowed by Different Types of Upper Extremity Immobilization

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Background: The purpose of this study was to compare the active forearm pronation and supination allowed by a short arm splint, short arm cast, sugar tong splint, long arm splint, and long arm cast in normal, healthy subjects.

Methods: Forty healthy, right-handed volunteers (twenty men and twenty women) with a mean age of thirty-five years (range, twenty-three to sixty-six years) were recruited. Two examiners used a goniometer developed for the study to measure the active forearm supination and pronation in each subject with and without the application of the different types of upper extremity immobilization. Forearm pronation and supination were compared among the immobilization methods and between men and women. The inter-rater reliability of the measurements was evaluated with use of the intraclass correlation coefficient.

Results: The long arm cast decreased active forearm rotation to <10% of the value with no immobilization. The short arm cast, sugar tong splint, and long arm splint decreased active forearm rotation to <40% of the baseline measurement. No significant difference in active forearm supination or pronation was observed among the short arm cast, sugar tong splint, and long arm splint in the overall study cohort or in the men. However, forearm supination and pronation in the women differed significantly between the short arm cast and both the sugar tong splint and the long arm splint.

Conclusions: The long arm cast provided the greatest restriction of forearm rotation. Overall, no significant difference in active forearm supination or pronation was observed among the short arm cast, sugar tong splint, and long arm splint.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

The short arm splint, short arm cast, sugar tong splint, long arm splint, and long arm cast are commonly used for the conservative treatment or postoperative management of upper extremity injuries. Restriction of forearm rotation has been recommended after distal radial fracture, distal ulnar fracture, distal radioulnar joint injury including a triangular fibrocartilage complex tear, and scaphoid fracture[1-4]. Some authors have reported that restriction of forearm rotation by a sugar tong splint is superior to that by other short arm immobilizers, while still allowing for some elbow flexion and extension (in contrast to long arm immobilizers)[1,4]. However, to our knowledge, the extent to which various immobilization methods limit forearm rotation has not been quantified. The purpose of this study was to compare active forearm pronation and supination after the application of a short arm splint, short arm cast, sugar tong splint, long arm splint, and long arm cast in normal, healthy subjects.

Materials and Methods

Subjects

Approval of the study protocol was obtained from our institutional review board prior to commencing the study. Forty healthy, right-handed volunteers

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TABLE I Active Forearm Rotation According to Immobilization Method

Method*	Rotation	Mean *(deg)*	Stand. Dev. *(deg)*	Percentage†	ICC‡
No immobilization	Pronation	94	7		0.94
	Supination	100	5		0.91
Short arm splint	Pronation	56	15	59	0.88
	Supination	55	15	55	0.90
Short arm cast	Pronation	34	10	36	0.93
	Supination	33	11	33	0.95
Sugar tong splint	Pronation	32	9	34	0.91
	Supination	31	10	31	0.86
Long arm splint	Pronation	31	10	33	0.96
	Supination	30	10	31	0.93
Long arm cast	Pronation	9	5	10	0.98
	Supination	8	3	8	0.95

*N = 40 subjects for each. †Percentage of the active forearm rotation with no immobilization. ‡ICC = intraclass correlation coefficient for inter-rater reliability.

(twenty men and twenty women) with a mean age of thirty-five years (range, twenty-three to sixty-six years) were recruited. The exclusion criteria were a positive history of an inflammatory or neurologic disease or of a traumatic event at or distal to the elbow that required treatment. All subjects were informed of the study aims and agreed to active participation.

Measurements

The custom-made goniometer (Fig. 1) consisted of three parts: (1) a circular goniometer plate with a scale to measure the angle and a handle connected to a marking pointer; (2) a forearm support; and (3) an upper arm support. The forearm support and upper arm support could be adjusted for variations in forearm length.

Before measuring the forearm rotation, Velcro banding was used to fix the upper arm tightly to the upper arm support to prevent shoulder rotation. Additionally, Velcro banding was applied to the proximal aspect of the forearm to prevent any movement of the forearm with the exception of rotation. The zero position was defined as 0° of shoulder abduction and rotation, 90° of elbow flexion, and neutral forearm rotation in the sitting position.

The short arm splint was constructed by applying a prefabricated 4 × 15-inch (10.2 × 38.1-cm) splint (Scotchcast Conformable Splint 72415; 3M, St. Paul, Minnesota) over one layer of cotton padding. The splint began just proximal to the metacarpophalangeal joint volarly and ended at the forearm 3 cm distal to the elbow flexion crease. A 4-inch (10.2-cm) elastic band was then applied tightly.

The short arm cast was constructed with use of 3-inch (7.6-cm) casting tape (Scotchcast Poly Plus Casting Tape 85003; 3M) spirally wrapped over a stockinette sleeve and one layer of cotton padding. The cast began just proximal to the volar and dorsal aspects of the metacarpophalangeal joint and ended at the forearm 3 cm distal to the elbow flexion crease.

The sugar tong splint was constructed by applying a 3 × 35-inch (7.6 × 88.9-cm) prefabricated splint (Scotchcast Conformable Splint 72335; 3M) without the use of padding. The splint began slightly proximal to the metacarpophalangeal joint dorsally, extended around the elbow, and ended at the midpalmar region volarly. A 4-inch (10.2-cm) elastic bandage was then applied tightly.

The long arm splint was constructed by applying a 4 × 30-inch (10.2 × 76.2-cm) prefabricated splint (Scotchcast Conformable Splint 72430; 3M) over one layer of cotton padding. The splint started just proximal to the metacarpophalangeal joint on the ulnar side of the hand, extended to the ulnar side of the forearm and elbow joint, and ended at the proximal one-third of the upper arm. The splint was positioned with the elbow in 90° of flexion and the forearm in neutral rotation.

The long arm cast was constructed with use of 3-inch (7.6-cm) casting tape (Scotchcast Poly Plus Casting Tape 85003) applied over a stockinette sleeve and one layer of cotton padding. The cast started just proximal to the metacarpophalangeal joint, extended to the elbow joint, and ended at the proximal one-third of the upper arm. The cast was positioned with the elbow in 90° of flexion and the forearm in neutral rotation.

Active forearm rotation was measured by two examiners. The subject was instructed to turn the handle of the goniometer with maximum strength until the same loading was felt while wearing each immobilization device. For each subject, we first measured active forearm pronation and supination of the bare forearm with no immobilization applied and then repeated the procedure with each type of immobilization. The order of testing for the different types of

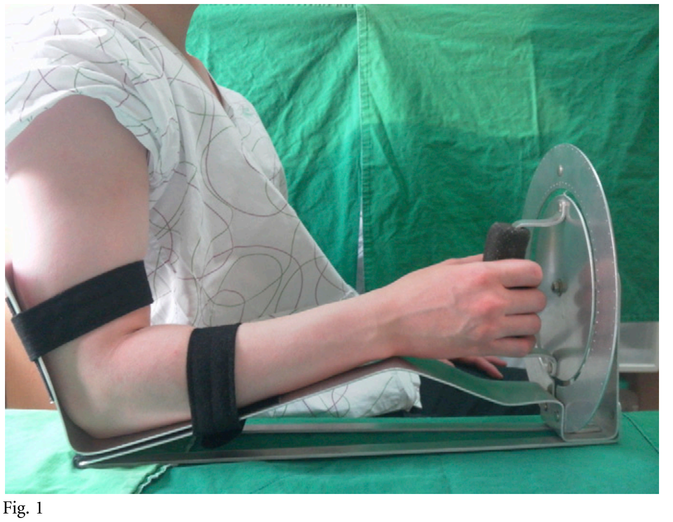

Fig. 1

Custom-made goniometer for the measurement of active forearm supination and pronation.

TABLE II Significance of Differences in Active Forearm Rotation Between Immobilization Methods

Comparison	Rotation	P Value
No immobilization vs. short arm splint	Pronation	<0.001
	Supination	<0.001
Short arm splint vs. short arm cast	Pronation	<0.001
	Supination	<0.001
Short arm splint vs. sugar tong splint	Pronation	<0.001
	Supination	<0.001
Short arm splint vs. long arm splint	Pronation	<0.001
	Supination	<0.001
Short arm cast vs. sugar tong splint	Pronation	0.48
	Supination	0.21
Short arm cast vs. long arm splint	Pronation	0.08
	Supination	0.06
Short arm cast vs. long arm cast	Pronation	<0.001
	Supination	<0.001
Sugar tong splint vs. long arm splint	Pronation	0.14
	Supination	0.12
Sugar tong splint vs. long arm cast	Pronation	<0.001
	Supination	<0.001
Long arm splint vs. long arm cast	Pronation	<0.001
	Supination	<0.001

immobilization was determined by means of permuted block randomization generated by an independent research assistant with use of an Internet-based computerized random-sequence generator[5].

Sample Size

A sample size of thirty-three patients was calculated to be necessary to provide >80% power to detect a minimum difference of 5° in the range of forearm rotation among different types of immobilization, assuming a standard deviation of 10°.

Statistical Analysis

The Wilcoxon signed-rank test was used to compare the ranges of forearm pronation and supination among the different immobilization methods. The Mann-Whitney U test was used to compare the ranges of the men and the women for each immobilization method. All statistical tests were two-sided, and a p value of <0.05 was considered significant.

The inter-rater reliability of the measurements made by the two examiners was evaluated with use of the intraclass correlation coefficient (ICC). The ICC was considered low if it was <0.40, moderate if it was ≥0.40 but <0.75, and high if it was ≥0.75[6].

Source of Funding

There was no external funding source for this study.

Results

The active forearm pronation and supination data from the two observers were used to calculate the mean and standard deviation for each immobilization method (Table I). The ICC for the inter-rater reliability of the active forearm supination and pronation measurements was >0.80 (high) for all methods.

When the short arm splint was applied, active forearm supination and pronation decreased to 55% and 59%, respectively, of the value with no immobilization ($p < 0.001$). The short arm cast, sugar tong splint, and long arm splint further decreased active forearm supination and pronation ($p < 0.001$ compared with the short arm splint). The range of active forearm supination and pronation was most substantially restricted when the long arm cast was applied.

When the short arm cast was applied, active forearm supination and pronation decreased to 33% and 36%, respectively, of the value with no immobilization. When the sugar tong splint was applied, active forearm supination and pronation decreased to 31% and 34% of the value with no immobilization. When the long arm splint was applied, active forearm supination and pronation decreased to 31% and 33% of the value with no immobilization. No significant differences were observed between the active forearm supination ($p = 0.21$) and pronation ($p = 0.48$) allowed by the short arm cast and by the sugar tong splint (Table II). No significant differences were observed between the active forearm supination ($p = 0.06$) and pronation ($p = 0.08$) allowed by the short arm cast and by the long arm splint. No significant differences were observed between the active forearm supination ($p = 0.12$) and pronation ($p = 0.14$) allowed by the sugar tong splint and by the long arm splint.

Forearm supination and pronation differed significantly between men and women in only two cases, no immobilization and immobilization in the short arm cast (Table III). Forearm supination and pronation in men did not differ between the short arm cast and either the sugar tong splint ($p = 0.32$ and 0.49, respectively) or the long arm splint ($p = 0.12$ and 0.23) (Fig. 2-A). However, forearm supination and pronation in women did differ significantly between the short arm cast and

TABLE III Active Forearm Rotation for Each Immobilization Method According to Sex

		Range of Motion *(deg)*		
Method	Rotation	Men	Women	P Value
No immobilization	Pronation	91 ± 6	98 ± 8	<0.001
	Supination	98 ± 3	102 ± 8	<0.001
Short arm splint	Pronation	53 ± 16	60 ± 15	0.17
	Supination	53 ± 15	58 ± 14	0.17
Short arm cast	Pronation	31 ± 7	38 ± 11	0.01
	Supination	30 ± 8	36 ± 12	0.03
Sugar tong splint	Pronation	31 ± 9	33 ± 5	0.64
	Supination	30 ± 10	32 ± 11	0.56
Long arm splint	Pronation	29 ± 10	33 ± 14	0.10
	Supination	28 ± 9	32 ± 10	0.08
Long arm cast	Pronation	9 ± 3	10 ± 6	0.47
	Supination	8 ± 4	7 ± 2	0.42

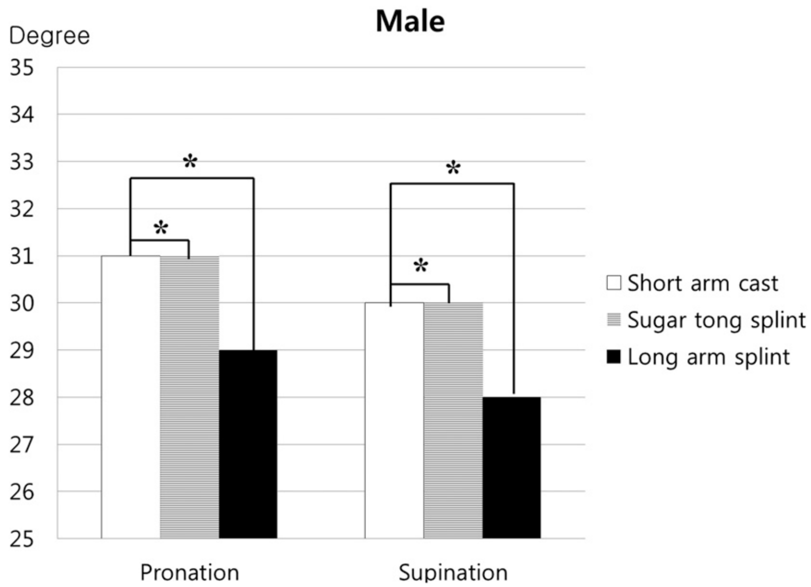

Fig. 2-A

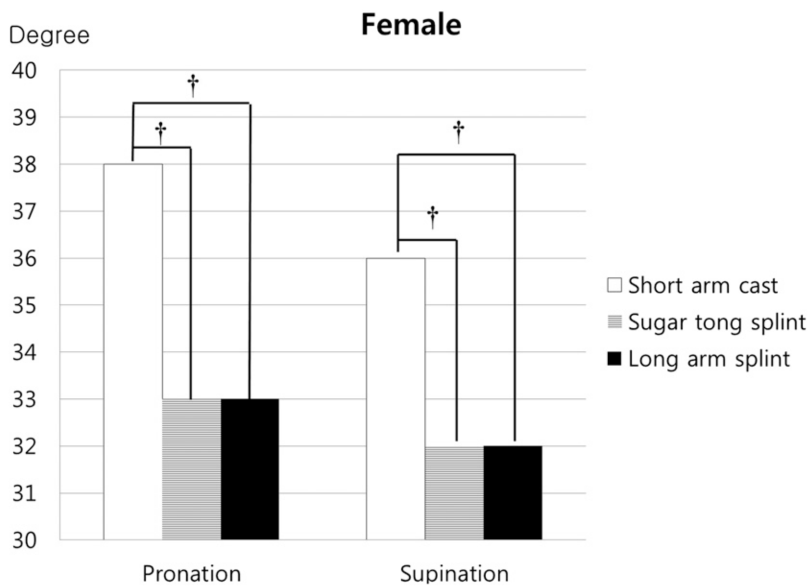

Fig. 2-B

Fig. 2-A In men, the restriction of active forearm supination and pronation did not differ significantly between the short arm cast and either the sugar tong splint or the long arm splint. $^*P \geq 0.05$. **Fig. 2-B** In women, active forearm supination and pronation were restricted significantly less by the short arm cast than by either the sugar tong splint or the long arm splint. $^\dagger P < 0.05$.

both the sugar tong splint and the long arm splint ($p < 0.05$ for both supination and pronation for each) (Fig. 2-B).

Discussion

Numerous types of injuries, including distal radioulnar joint injuries, heal better when forearm rotation is limited[1,2,4]. Forearm rotation can have an adverse effect on the healing of damaged distal radioulnar joint ligaments for several reasons. First, forearm rotation can cause changes in the lengths of the palmar and dorsal radioulnar ligaments[7,8], which are considered to be the primary stabilizers of the distal radioulnar joint[9]. The dorsal superficial radioulnar ligaments and palmar deep radioulnar ligaments are stressed during forearm pronation, and the palmar superficial radioulnar ligaments and dorsal deep radioulnar ligaments are stressed during forearm supination[7]. Second, forearm rotation causes proximal and distal translation of the distal aspect of the radius relative to the ulnar head, which can be observed as decreased ulnar variance in supination compared with pronation[10]. Third, forearm rotation produces translation between the sigmoid notch and the ulnar head in the palmar-dorsal direction, so that the ulnar head is somewhat palmar relative to the radius during supination and dorsal to it during pronation[11]. For the above reasons, restriction of forearm supination and pronation has been recommended following distal radioulnar joint injury.

The present study demonstrated that the long arm cast provided the greatest restraint to forearm rotation, permitting <10% of normal forearm supination and pronation. The short arm cast, sugar tong splint, and long arm splint were found to decrease forearm supination and pronation to approximately 30% to 40% of the normal value, but no significant differences among these three types of immobilization were found in the overall study cohort. The effect of the short arm splint was less than those of the other immobilizers, resulting in a decrease in forearm supination and pronation to approximately 57% of the normal level.

Previous studies of forearm rotation in normal subjects indicated that women have a greater arc of forearm supination and pronation compared with men[12,13], which is consistent with our findings. This may be explained by greater general laxity of the relevant connective tissue in women, including radioulnar joint stabilizers such as the joint capsule, ligaments, and interosseous membrane, as has been observed at other joints[14,15]. Our study also demonstrated significant differences in forearm supination and pronation between men and women when the short arm cast was applied. Furthermore, forearm supination and pronation differed significantly between the short arm cast and both the sugar tong splint and the long arm splint in women but not in men.

Because the sugar tong splint and long arm splint extend over the proximal radioulnar joint and the distal radioulnar joint, these methods have been thought to be superior to the short arm splint or short arm cast with regard to limiting forearm pronation and supination. Furthermore, the sugar tong splint permits some elbow flexion and extension, whereas the long arm splint and long arm cast do not. For these reasons, the sugar tong splint is popularly used to treat wrist injuries such as distal radial fractures and distal radioulnar joint injuries. However, this study revealed that the short arm cast, sugar tong splint, and long arm splint offered similar levels of restriction of forearm pronation and supination.

We propose the following explanation for this finding. The sugar tong splint and long arm splint extend beyond the wrist joint and proximal radioulnar joint, but they do not cover these joints fully. On the other hand, the short arm cast partially includes the proximal radioulnar joint, and it completely covers the wrist joint and forearm muscle structures because it ends 3 cm distal to the elbow flexion crease and the proximal end of the radial head is located only 2.2 cm distal to the elbow flexion crease[16]. Because of these structural differences, the sugar tong splint and long arm splint are superior to the short arm cast for limiting rotational movement of the proximal radioulnar joint, whereas the short arm cast is superior for limiting the rotational movement of the distal radioulnar joint as well as forearm muscle and interosseous membrane abutment. As the pronation and supination allowed by the short arm cast differed significantly between men and women, we speculate that prevention of forearm muscle and interosseous membrane abutment may play a role in the ability of the short arm cast to limit forearm rotation.

All immobilization techniques involve a certain degree of inconvenience, but some cause more discomfort than others[1,17]. In a prospective randomized study of distal radial fracture treatment methods, Bong et al.[1] reported that patients treated with a short arm splint had significantly better Disabilities of the Arm, Shoulder and Hand (DASH) scores than patients treated with a sugar tong splint. This observation by Bong et al. and our observation that forearm rotation limitation by the short arm cast, sugar tong splint, and long arm splint was comparable indicate that the short arm cast would be better than the sugar tong splint or long arm splint in a clinical situation in which the object of the immobilization is limitation of forearm rotation and wrist motion.

This study has several limitations. First, carpal rotation occurs at the midcarpal and radiocarpal joints. Gupta and Moosawi[18] reported that mean supination and pronation at the midcarpal and radiocarpal joints is approximately 17° when no immobilizer is applied. Although we believe that the effect of carpal rotation was minimized in our study because all of the upper arm immobilizers extended beyond the radiocarpal and midcarpal joints, it is still possible that restriction of carpal rotation was not consistent among the immobilization methods. Second, we used prefabricated splints. This could have had an effect on the resulting limitation of forearm rotation, although we made our best effort to reduce this effect by molding the splints like custom-molded splints. Third, measuring the active range of motion that a healthy subject can achieve with full effort does not replicate the situation following an arm injury; the arms that we studied were normal and therefore did not have swelling or other symptoms that may affect the ability to properly mold the cast or splint. Fourth, the force exerted by the individual subjects was not standardized. Finally, the 4° to 5° difference in mobility between the short arm cast and both the long arm splint and the sugar tong splint in women may not be clinically relevant.

In summary, if surgeons wish to reduce forearm rotation as much as possible, they should use a long arm cast. The short arm cast, sugar tong splint, and long arm splint had comparable effects on forearm rotation, reducing it by two-thirds; if this amount of forearm rotation is acceptable for treatment of an injury, any of these three immobilization methods can be used. Finally, the short arm splint reduced rotation by less than one-half and should be used only in situations in which this amount of rotation limitation is acceptable during healing of the wrist or hand injury. ■

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