Optoelectronic measurement of wrist movements in various casts and orthoses used in scaphoid fractures.

Andrew Waton, Sarah Forrest, Gemma M.Whatling

Cardiff School of Engineering, Cardiff University, Cardiff, UK

Corresponding Author

Gemma Whatling

Cardiff School of Engineering, Cardiff University, Cardiff, United Kingdom

02920876348

whatlinggm@cardiff.ac.uk

Key words: Scaphoid fracture, immobilisation, Scaphoid cast, Colles' cast, optoelectronic

ABSTRACT

We developed an optoelectronic motion analysis protocol to measure anatomical and functional ranges of wrist motion in Colles'-type and scaphoid-type splints and casts. The protocol was used to study the restriction of wrist motion in casts and splints in ten healthy volunteers. Scaphoid-type casts were no more restrictive to wrist motion than Colles'-type casts, but casts were significantly more restrictive than removable splints. Removable splints were more restrictive than no immobilization. Results suggest there is no benefit in using scaphoid-type casts rather than Colles'-type casts to reduce wrist motion.

INTRODUCTION

Management of stable fractures of the scaphoid remains controversial with some surgeons advocating operative stabilization, whilst others advocate treatment in a variety of plaster casts, splints or supportive bandages. (Geissler et al., 2012; Rhemrev et al., 2011; Sjølin and Andersen, 1988; Terkelsen and Jepsen, 1988). When comparing two commonly used casts, the randomized controlled trial of Clay et al. (1991) showed no difference in union rate 6 months after scaphoid fracture when using Colles' or scaphoid casts. In addition, a systematic review and meta-analysis of the limited number of randomized controlled trials found no significant difference in the rate of nonunion when using the Colles'-type and scaphoid-type casts (Doornberg et al., 2011).

We can investigate the effectiveness of casts and splints by measuring how much they limit motion. Three-dimensional optoelectronic methods allow movement to be quantified without the need for ionizing radiation (Small et al., 1996). They can be used to measure the motion of the wrist as a whole, rather than the scaphoid directly.

To provide biomechanical evidence for the debate surrounding the various methods of splinting used in the treatment of acute scaphoid fractures, we have used optoelectronic methods to compare the ranges of movement in the wrist within a variety of casts and splints.

METHODS

Ten healthy right-hand dominant volunteers aged 18 to 45 (mean 28) years were recruited and informed consent taken. They had no previous wrist injury or disability, quantified by normal results in two validated wrist function scores: the Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH) (Hudak et al., 1996) and the Patient-Rated Wrist Evaluation (PRWE) (MacDermid, 1996) scores. These were selected as two recent systematic reviews found them to be reliable and responsive, with high validity, for patients with wrist injuries (Changulani et al., 2008; Hoang-Kim et al., 2011). Ethical approval was obtained from the Cardiff University School of Engineering ethics committee.

Wrist motion was measured in seven types of restriction, referred to as casts *a* to *g*, as detailed in Table 1.

A range of sizes of the two removable splits (Actimove® Manus Eco, BSN Medical UK Limited, Hull, UK and the Carpus Wrist and Thumb Brace 841, Red Box Orthotics, Quintex (UK) Limited) were available, and correct fitting was confirmed by the lead author (A.W.) in each case. All casts were constructed in a standard fashion by the lead author, with a single roll of synthetic padding (Soffban Natural®, 10cm, Smith and Nephew UK Limited, London, UK) then Gypsona BP® plaster of Paris 5cm rolls (BSN Medical UK Limited, Hull, UK), or with 5cm rolls of Delta-Cast Elite® (BSN Medical UK Limited, Hull, UK) in place of the Gypsona® rolls.

A comparison of plaster of Paris (POP) and synthetic casting material was made as mechanical tensile strength and four-point bending tests on POP and a synthetic casting material have shown that POP is more than twice as stiff as the synthetic cast (Mihalko et al., 1989).

Six ProReflex MCU 1000 Motion Capture Cameras (Qualysis AB, Gothenburg, Sweden) were used to measure location of rigid marker clusters positioned on the forearm and hand using a protocol modified from the work by Brigstocke et al. (2013; 2014). One cluster was positioned 35 mm proximal to the centre-point of the inter-styloid axis with two markers aligned perpendicular to the long axis of the forearm and the third marker aligned along the longitudinal axis (Figure 1a). The other cluster was positioned on the dorsum of the hand at the midpoint of the middle metacarpal where there is very little skin movement, unlike the radial and ulna styloids (Schmidt et al., 1999). Two markers were aligned perpendicular to the long axis of the middle metacarpal, with the third marker aligned along the longitudinal axis (Figure 1b). These marker placements minimize errors associated with pronation and supination (Schmidt et al., 1999), whilst allowing full range of wrist movement without impingement on the marker bases, or on the hand and forearm clusters. The bases were connected to a single post elevating the clusters above the surface of the cast or splint with minimal alteration to them. Casts and splints were fashioned with the bases in-situ: small holes were made in the splints to facilitate fitting over the marker bases, and casts were constructed with the bases in-situ, around a 10mm diameter spacer, to create a consistent round hole in the casts. This allowed us to ensure that the base was not moved between testing conditions, ensuring repeatability and comparability of measurements of wrist motion.

Clusters were custom-made with three 7 mm spherical markers, supported by 20 mm x 1 mm steel rods. Figure 2 shows examples of the completed casts and splints with markers in place.

Participants were instructed to carry out the movements of flexion and extension (FE), radio-ulnar deviation (RUD) and circumduction to determine the range of motion achievable. The functional tests assessed included opening a jar lid, pouring from a jar, drinking the last drops from a cup and simulated dart throwing motion (DTM). These were selected from previous studies (Brigstocke et al., 2014; Murgia et al., 2004) and the Southampton Hand Assessment Procedure (SHAP) (Light et al., 2002). The participants repeated each activity for 10 seconds resulting in approximately six repetitions.

Data recording during tasks was done using Qualysis Track Manager (Qualysis AB, Gothenburg, Sweden), then rigid bodies for the hand and forearm were created from the marker locations, with local axis systems defined according to the Standardization of Terminology Committee of the International Society of Biomechanics (ISB) Recommendations (Wu et al., 2004). The axis systems used in this study are shown in Figure 3.

After definition of the hand and forearm rigid bodies, wrist motion with six degrees of freedom was calculated. Euler angles describing the rotation of the hand axis system relative to the forearm axis system were calculated. The focus of this study is radio-ulnar deviation (defined as *roll* around the x-axis), with ulnar deviation being a positive rotation, and flexion-extension (defined as *yaw* around the z-axis), with flexion being positive.

Statistical methods

The roll and yaw data collected throughout each activity was filtered using standard approaches (a Fourth Butterworth Low-Pass filter with a cut-off set to 15 Hz). This step reduced noise in the kinematic data, which occurs when using optoelectronic methods and skin mounted markers. The start and end time of each task cycle was manually selected and the range of motion (ROM) calculated for each task cycle about each of the axes using a semi-automated program created in MATLAB® (2008. MathWorks. Natick, MA, USA.). The median value was calculated for each of the seven tasks and casting conditions.

The Shapiro-Wilk test of normality found that there was significant deviation from the normal distribution for all of the tasks across each cast group. Levene's test for homogeneity of variance found that the groups did not have equal variance either. Normality could not be achieved though transformations of the data, so statistical analysis was carried out using Friedman's non-parametric related samples two-way analysis of variance by ranks, with pair-wise comparisons between each cast group done with a post-hoc Dunn-Bonferroni test. A Bonferroni adjustment was made to the *p*-value as there were multiple comparisons. The α value was set to 0.05. Statistical analysis was done using SPSS version 20 (2011. IBM Corp, Armonk, NY, USA) to compare tasks and casts.

RESULTS

Table 2 shows ROM for roll and yaw from each of the seven tasks. The Friedman test revealed statistically significant differences between the seven casting conditions during each of the activities. Table 3 displays the comparisons between casting conditions. ROM was reduced using splints and reduced significantly further using casts. The ROM observed in the free condition (cast *a*) during range of motion and functional tasks are similar to those reported in previous studies, summarized in Table 4.

There was a consistent statistically significant reduction (p<0.001) of range of flexion-extension and ulnar-radial deviation in the plaster casts (casts *d* to *g*) relative to the free condition (cast *a*) and the two splints (casts *b* and *c*). The only exception to this was for the comparison made between the scaphoid-type synthetic casts and splints where the difference was not significantly different (p=0.582) for flexion-extension during the pouring task. It can however, be seen from Table 2 that the synthetic cast reduces the ROM to a greater degree than the splint.

Wrist motion in all casting conditions did not exceed 4° of radio-ulnar deviation or 9° of flexion-extension during range of motion tests, and did not exceed 2°of radio-ulnar deviation or 4°of flexion-extension during functional tests. Colles' and scaphoid casts performed similarly with no significant difference in ROM, as did similar types of casts made with different materials (POP vs synthetic).

Removable splints reduced ROM for all activities with statistically significant reductions in radio-ulnar deviation ROM in all tasks, except for the flexion-extension task, and a significant reduction in flexion-extension ROM during circumduction (for both Colles' and scaphoid splints), pouring and radial-ulnar deviation tasks (for the scaphoid splint). In the functional assessments, the smallest reduction in flexion-extension ROM was during the drinking task ($<5^{o}$) and the smallest reduction in radial-ulnar deviation was during the drinking and DTM tasks.

Throughout all of the ROM and functional tests, there was no significant difference between Colles'-type and scaphoid-type casts.

DISCUSSION

This study reports a 3D marker based approach that can be used to measure wrist motion in the presence of plaster casts and splints in-vivo. The results provide additional information to what is known about wrist kinematics for a range of casting conditions. We have shown that scaphoid-type casts are no more restrictive to wrist motion than Colles'-type casts, but that both types of cast are significantly more restrictive than removable splints. Removable splints are more restrictive than no immobilization at all. There was no significant difference in the ROM between the POP and synthetic casts. The difference in stiffness between the two casting materials does not appear to be significant with respect to wrist motion.

In the free wrist condition, functional tasks, with the exception of the dart throwing motion, showed a greater involvement of radio-ulnar deviation than flexion-extension, which is in contrast to the summarized studies (Table 4). This may be due to different methodological approaches and instructions given for each activity. Palmer et al. (1985) and Ryu et al. (1991) used electrogoniometers to measure functional motion. The other studies used optoelectronic measurements in which the marker placements and testing protocols are not standarized, either between the studies or the current study.

This study found no difference between Colles'-type and scaphoid-type immobilization, suggesting that in terms of restricting movement of the wrist, there is no additional benefit provided by incorporating the thumb when casting. These findings link with the results from clinical studies indicating no differences between the scaphoid and Colles' casts in union after acute scaphoid fractures (Clay et al., 1991; Doornberg et al., 2011).

In addition, Karantana et al. (2006) concluded that there was significant functional impairment caused by the use of scaphoid-type casts compared to Colles' casts, demonstrated by a significant increase in the time taken to complete the Jebson-Taylor series of standardized hand function tests in 20 healthy volunteers. These studies and the present investigation suggest that the scaphoid casts may not have a role in the non-operative management of acute fractures of the scaphoid waist.

In all the tasks, there was a significantly larger range of wrist motion in splints than in casts. This is because splints provide resistance to motion using one aluminium strut on the flexor aspect with the Colles'-type splint and a second on the radial side with the scaphoid-type splint, whereas plaster casts encase the whole wrist. This finding suggests that removable splints may also not have a role in the nonoperative management of acute scaphoid fracture, as the greater wrist motion may lead to an increase in the occurrence of nonunion of fractures. A randomized clinical trial would be the best way to confirm or refute this theory. Nevertheless Terkelsen and Jepson (1988) and Sjølin and Andersen (1988) found no difference in union between casts and splints. This questions what movement during immobilization is acceptable in the healing process.

A limitation to this study is the use of a healthy population and therefore the results may not be representative of the clinical picture in patients with scaphoid fracture.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical Approval

Ethical approval for the use of volunteers in the study was obtained from the Cardiff University School of Engineering ethics committee.

Informed consent

A detailed Volunteer Information Sheet explaining the experiment and the role of the volunteers in the study was provided to be read by the volunteer prior to commencement. A consent form was signed by all volunteers prior to testing.

REFERENCES

Brigstocke GHO, Hearnden A, Holt C, Whatling G. The functional range of movement of the human wrist. J Hand Surg Eur. 2013, 38: 554-6.

Brigstocke GHO, Hearnden A, Holt C, Whatling G. In-vivo confirmation of the use of the dart thrower’s motion during activities of daily living. J Hand Surg Eur. 2014, 39: 373-8.

Changulani M, Okonkwo U, Keswani T, Kalairajah Y. Outcome evaluation measures for wrist and hand – which one to choose? Int Orthop. 2008, 32: 1-6.

Clay NR, Dias JJ, Costigan PS, Gregg PJ, Barton NJ. Need the thumb be immobilised in scaphoid fractures? J Bone Joint Surg Br. 1991, 73: 828-32.

Doornberg JN, Buijze GA, Ham SJ, Ring D, Bhandari M, Poolman RW. Nonoperative treatment for acute scaphoid fractures: A systematic review and meta-analysis of randomized controlled trials. J Trauma. 2011, 71: 1073-81.

Geissler WB, Adams JE, Bindra RR, Lanzinger WD, Slutsky DJ. Scaphoid fractures: What's hot, what's not? American Academy of Orthopaedic Surgeons instructional course lecture. J Bone Joint Surg Am. 2012, 94: 168-81.

Hoang-Kim A, Pegreffi F, Moroni A, Ladd A. Measuring wrist and hand function: Common scales and checklists. Injury. 2011, 42: 253-8.

Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: The DASH (Disabilities of the arm, shoulder and hand). Am J Ind Med. 1996, 29: 602-8.

Karantana A, Downs-Wheeler MJ, Webb K, Pearce CA, Johnson A, Bannister GC. The effects of scaphoid and Colles casts on hand function. J Hand Surg Br. 2006, 31: 436-8.

Light CM, Chappell PH, Kyberd PJ. Establishing a standardized clinical assessment tool of pathologic and prosthetic hand function: Normative data, reliability, and validity. Arch Phys Med Rehabil. 2002, 83: 776-83

MacDermid JC. Development of a scale for patient rating of wrist pain and disability. J Hand Ther. 1996, 9: 178-83.

Mihalko WM, Beaudoin AJ, Krause WR. Mechanical properties and material characteristics of orthopaedic casting material. J Orthop Trauma. 1989, 3: 57-63.

Murgia A, Kyberd PJ, Chappell PH, Light CM. Marker placement to describe the wrist movements during activities of daily living in cyclical tasks. Clin Biomech. 2004, 19: 248-54.

Palmer AK, Werner FW, Murphy D, Glisson R. Functional wrist motion: A biomechanical study. J Hand Surg Am. 1985, 10: 39-46.

Rhemrev SJ, Ootes D, Beeres FJPO, Meylaerts SAG, Schipper IB. Current methods of diagnosis and treatment of scaphoid fractures. Int J Emerg Med. 2011: 4: 4.

Ryu JY, Cooney WP, Askew LJ, An KN, Chao EY. Functional ranges of motion of the wrist joint. J Hand Surg Am. 1991, 16: 409-19.

Schmidt R, Disselhorst-Klug C, Silny J, Rau G. A marker-based measurement procedure for unconstrained wrist and elbow motions. J Biomech. 1999, 32: 615-21.

Sjølin SU, Andersen JC. Clinical fracture of the carpal scaphoid – supportive bandage or plaster cast immobilization? J Hand Surg Br. 1988, 13: 75-6.

Small CF, Bryant JT, Dwosh IL, Griffiths PM, Pichora DR, Zee B. Validation of a 3D optoelectronic motion analysis system for the wrist joint. Clin Biomech. 1996, 11: 481-3.

Terkelsen CJ, Jepsen JM. Treatment of scaphoid fractures with a removable cast. Acta Orthop Scand. 1988, 59: 452-3.

Wu G, van der Helm FC, Veeger HE et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion – Part II: Shoulder, elbow, wrist and hand. J Biomech. 2004, 38: 981-92.

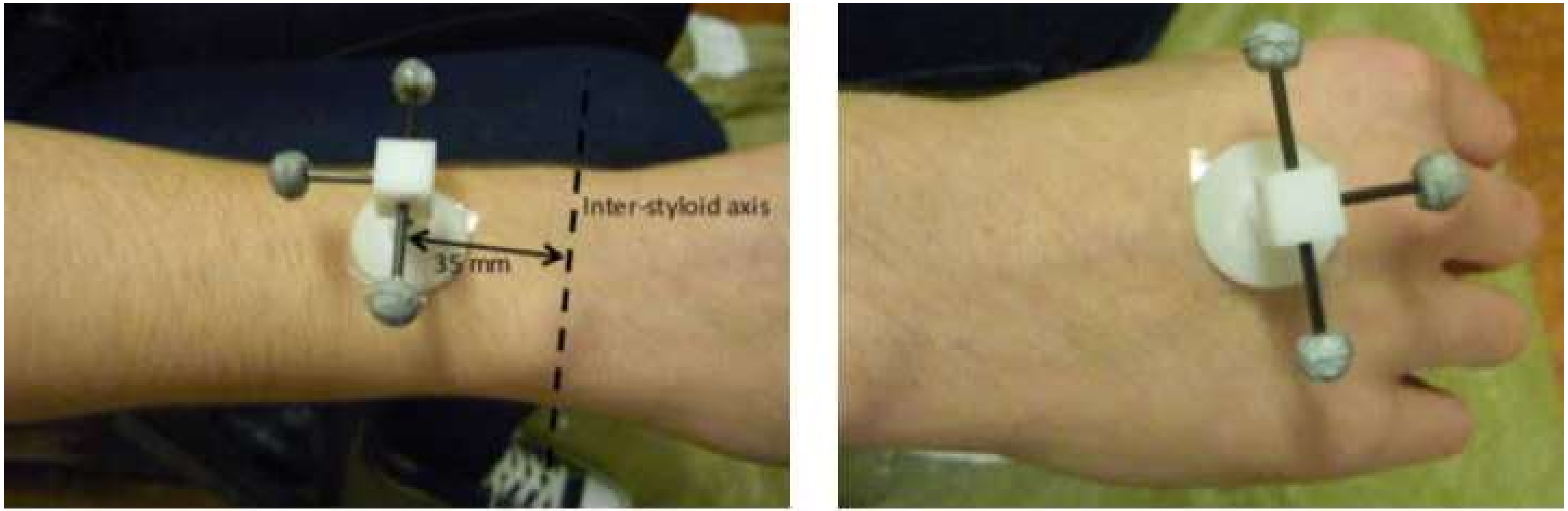
FIGURE LEGENDS

Figure 1. Marker cluster placements on (a) forearm and (b) hand.

Figure 2. Examples of completed casts and splints with marker clusters in place

Figure 3. Axis systems used to define motion. The figure demonstrates the dorsum of the right hand and forearm. Arrows indicate the positive axis directions. The x-axis lies perpendicular to the y- and z-axes and is positive in the direction dorsal to palmar.

Fig. 1



(a) (b)

Fig. 2

Fig.3

Click here to access/download;Figure(s);Fig.3.jpg

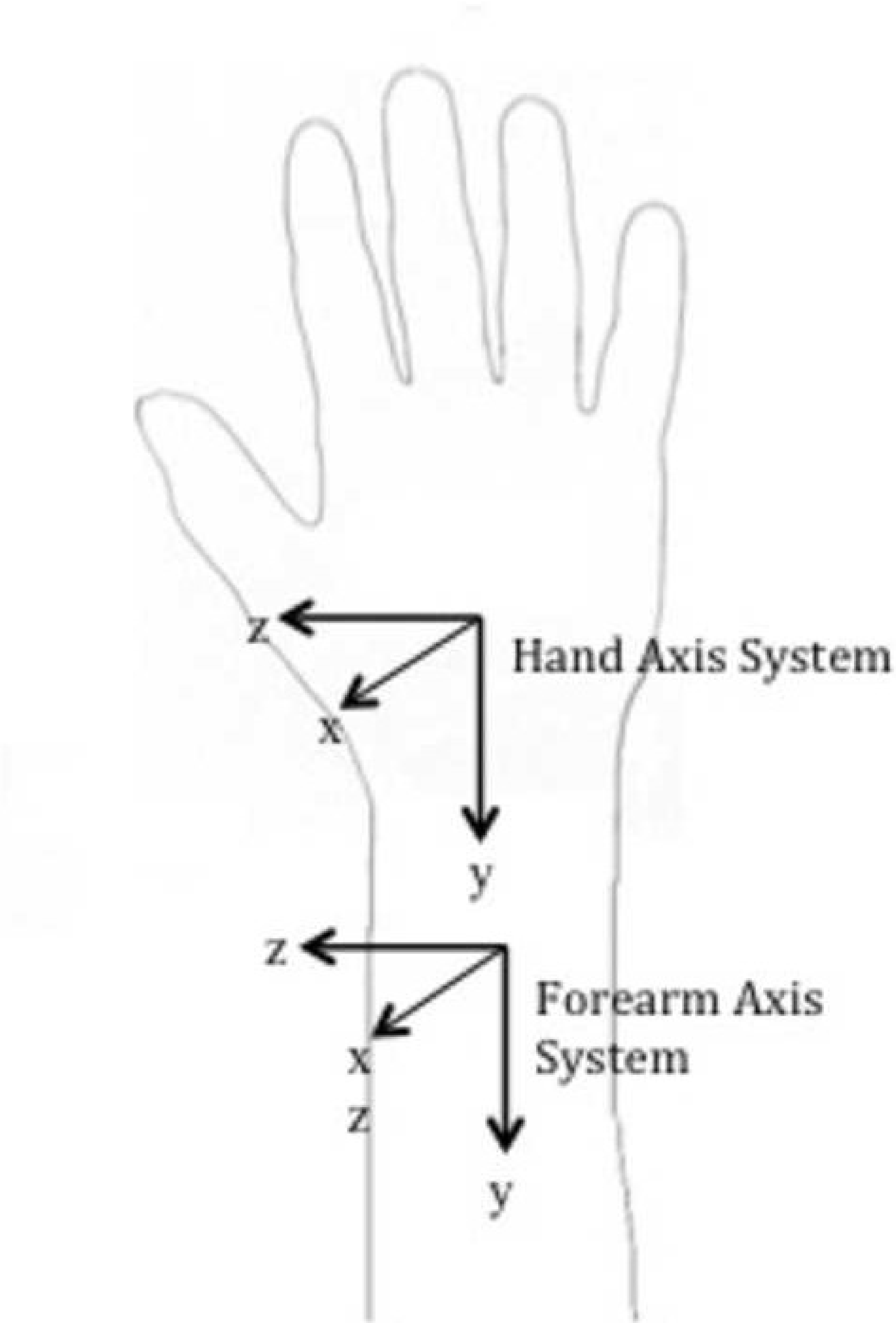


Table 1 . Casts: the various restrictions tested.

Cast	Restriction
a	Wrist free
b	Colles'-type removable splint
c	Scaphoid-type removable splint
d	Colles'-type cast – plaster of Paris
e	Scaphoid-type cast – plaster of Paris
f	Colles'-type cast – synthetic
g	Scaphoid-type cast – synthetic

Table 2

Table 2. Ranges of rotation for roll and yaw from each of the seven tasks for each cast. All rotations are shown as median (IQR) in degrees.

	Flex-extension		R/U deviation		Circumduction		Opening jar	
Cast	Roll	Yaw	Roll	Yaw	Roll	Yaw	Roll	Yaw
a	27	139	69	49	63	105	47	23
	(21 – 39)	(89 – 153)	(61 – 76)	(32 – 58)	(57 – 69)	(94 – 128)	(40 – 53)	(13 – 33)
b	12	50	34	22	30	45	20	14
	(10 – 15)	(45 – 75)	(25 – 42)	(15 – 31)	(16 – 37)	(40 – 53)	(15 – 26)	(9 – 21)
c	17	57	29	13	25	45	19	9
	(8 – 21)	(49 – 63)	(20 – 38)	(7 – 23)	(20 – 36)	(35 -53)	(14 – 24)	(6 – 19)
d	2	8	2	3	4	6	1	4
	(1 – 2)	(4 – 9)	(1 – 3)	(2 – 3)	(2 – 5)	(4 – 8)	(1 – 2)	(3 – 5)
e	2	9	2	4	4	8	1	4
	(1 – 3)	(6 – 11)	(1 – 4)	(3 – 5)	(2 – 5)	(6 – 9)	(1 – 2)	(3 – 5)
f	2	7	2	3	3	5	1	3
	(1 – 2)	(4 – 9)	(2 – 3)	(2 – 4)	(2 – 4)	(2 – 8)	(1 – 2)	(2 – 5)
g	1	5	2	3	3	4	1	3
	(1 – 2)	(4 – 7)	(2 – 3)	(2 – 4)	(2 – 3)	(3 – 5)	(1 – 2)	(2 – 4)

	Pouring		Drinking		DTM	
Cast	Roll	Yaw	Roll	Yaw	Roll	Yaw
a	33	15	36	20	32	40
	(30 – 45)	(12 – 27)	(30 – 45)	(12 – 27)	(23 – 39)	(18 – 53)
b	7	7	21	18	16	14
	(13 – 25)	(11 – 31)	(13 – 25)	(11 – 31)	(4 – 20)	(6 – 42)
c	7	6	18	16	9	16
	(12 – 25)	(8 – 18)	(12 – 25)	(8 -18)	(4 – 23)	(5 – 32)
d	2	4	1	3	1	4
	(1 – 2)	(2 – 5)	(1 – 2)	(2 – 5)	(1 – 3)	(3 – 5)
e	2	4	1	3	2	4
	(1 – 2)	(3 – 5)	(1 – 2)	(3 – 5)	(1 – 2)	(3 – 6)
f	2	4	1	3	2	4
	(1 – 2)	(2 – 5)	(1 – 2)	(2 – 5)	(1 – 3)	(2 – 6)
g	3	4	1	3	2	4
	(1 – 1)	(2 – 4)	(1 – 1)	(2 – 4)	(1 – 2)	(3 – 4)

IQR: interquartile range, DTM: dart-throwing motion

Table 3

Table 3:. Summary of Bonferroni adjusted *p*-values indicating significant differences between casting conditions.

Cast condition		Flex-extension	R/U deviation	Circumduction	Opening Jar	Pouring	Drinking	DTM
Comparing free and treatment								
Colles' splint vs free	Roll	0.121	**0.012**	**0.004**	**0.020**	**0.009**	**0.050**	**0.011**
	Yaw	0.104	0.220	**0.007**	1.000	0.098	1.000	0.233
Scaphoid splint vs. free	Roll	0.970	**0.003**	**0.004**	**0.017**	**0.020**	**0.011**	**0.011**
	Yaw	0.088	**<0.001**	**<0.001**	0.490	**0.001**	0.757	0.060
Colles' POP cast vs free	Roll	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Colles' syn cast v. free	Yaw	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Scaphoid POP cast v. free								
Scaphoid syn cast v. free								
Comparing casts and splints								
Colles' POP vs Colles' splint	Roll	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Scaphoid POP vs Scaphoid splint	Yaw	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Colles' syn vs Colles' splint								
Scaphoid syn vs Scaphoid splint	Roll	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Yaw	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.582	**<0.001**	**<0.001**
Comparing splints								
Scaphoid vs Colles' splints	Roll	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Yaw	1.000	0.717	1.000	1.000	1.000	1.000	1.000
Comparing casts								
Colles' vs Scaphoid POP casts	Roll	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Yaw	0.758	0.406	1.000	1.000	1.000	1.000	1.000
Colles' vs Scaphoid syn casts	Roll	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Yaw	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Comparing casting materials								
Colles' POP vs Colles' syn cast	Roll	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Yaw	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Scaphoid POP vs Scaphoid syn Cast	Roll	0.587	1.000	0.401	1.000	1.000	1.000	1.000
	Yaw	1.000	1.000	0.103	1.000	0.664	1.000	1.000

Roll: range of radio-ulnar (R/U) deviation; Yaw: range of flexion-extension. DTM: dart-throwing motion. POP: plaster of Paris; Syn: synthetic.

Significant *p*-values in bold font.

Table 4

Table 4. Comparison of ranges of motion observed in the free condition with previous studies (all in degrees).

Study		Flexion/ extension	Radio-ulnar deviation	Circumduction	Opening a jar	Pouring	Drinking	DTM
Current study	FE	129	-	104	23	14	20	40
	RUD	-	68	63	47	33	35	32
Brigstocke et a.l (2013)	FE	132			46	52	41	
	RUD		65		47	46	44	
Crisco et al. (2005)	FE	129	-					
	RUD	-	-					
Li et al. (2005)$	FE	128 (104- 149)	-	100				
	RUD	-	59 (52-68)	52				
Moritomo et al. (2000)	FE	135	-					
	RUD	-	51					
Palmer et al. (1985)	FE				35*	35*	35*	35*
	RUD				25*	25*	25*	25*
Ryu et al. (1991)	FE	-	-		40	40	18	
	RUD	-	-		47	19	15	

FE; Flexion/Extension, RUD: Radio-ulnar deviation, DTM: dart-throwing motion.

*Palmer et al. (1985) reported the functional range of motion of 52 functional tasks but did not report individual ranges for each task

$Li et al. (2005) report their own results with a summary of six other studies