Clinical Biomechanics 68 (2019) 109–113

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Wrist kinetics after scaphoidectomy

J. López-Valenciano[1,*], L. Aguilella[2], D. Montaner-Alonso[3], M. Llusá-Pérez[4,5], A. Lluch-Bergadà[6], M. Garcia-Elias[6]

[1] Hospital de Manises, Valencia, Avenida de la Generalitat Valenciana 50, 46940 Manises, Spain
[2] Hospital Universitario de La Ribera, Carretera de Corbera km 1, 46600 Alzira, Spain
[3] Hospital Universitario Doctor Peset, Avenida de Gaspar Aguilar 90, 46017 Valencia, Spain
[4] Departamento de Anatomía, Universidad de Barcelona, Carrer de Villarroel 170, 08036 Barcelona, Spain
[5] Hospital Clínico de Barcelona, Carrer de Villarroel 170, 08036 Barcelona, Spain
[6] Institut Kaplan, Paseo de la Bonanova 9, 2° 2ª, 08022 Barcelona, Spain

ARTICLE INFO

Keywords:
Carpus
Instability
Kinetics
Scaphoid
Scaphoidectomy
Wrist

ABSTRACT

Background: The scaphoid cannot be excised without generating substantial carpal dysfunction. The extent and nature of such a destabilizing procedure, however, has never been properly studied in the laboratory.
Methods: We used a six-degrees-of-freedom motion tracking device to quantify the changes in carpal alignment produced by isometric simultaneous loading of five wrist motor tendons in 12 fresh normal cadaver arms, before and after excising the entire scaphoid.
Findings: In the intact wrist, tendon loading consistently extended and supinated the capitate while flexing the triquetrum. After scaphoidectomy, the opposite rotations were always found: the capitate collapsed into flexion and pronation, whereas the triquetrum migrated proximally, while extending and radial deviating. All these changes were statistically significant.
Interpretation: Unless it is supplemented by some sort of midcarpal stabilization, scaphoidectomy alone is much too aggressive as a procedure to be considered a treatment option for wrist osteoarthritis.
Level of evidence: Laboratory study. Not applicable.

1. INTRODUCTION

The wrist is a highly mobile articulation with a complex load bearing mechanism able to bear considerable forces and torques without losing its internal congruency. There are two prerequisites for it to achieve these two goals: an undisturbed joint geometry and a finely tuned sensorimotor system that guarantees proper interaction of the different joint stabilizers, capsule, ligaments and muscles (Palmer et al., 1985; Ruby et al., 1985 Ruby et al., 1988; Li et al., 1991; Short et al., 1995; Salva-coll et al., 2013). When loaded, all bones of a stable wrist displace within normal limits following specific patterns of motion. Once the load is discontinued, all of them go back to their original position (Foumani et al., 2009; Salva-coll et al., 2013). These are the two main features characterizing kinetic instability: the inability to bear physiologic loads without yielding and the incapacity to return to its original alignment once unloaded.

Several in vitro investigations have assessed the kinetic consequences of different carpal pathologies including scaphoid nonunion and scapholunate instability (Mayfield, 1980; Mayfield et al., 1980; Vender et al., 1987; Watson and Ballet, 1984). Surprisingly, the effects of a complete scaphoid excision on the overall carpal mechanics have never been investigated. All we know is that, from a clinical point of view, it is preferable to excise the entire proximal row or to excise the scaphoid adding a partial arthrodesis, than just excise the scaphoid (Markiewitz and Stern, 2005; Mulford et al., 2009). The present study may help to understand why.

2. METHODS

Twelve fresh cadaver arms without visual detected pathology were utilized. The average age of the specimens was 76 years (range 72-80. There were four unpaired and eight paired arms, seven left wrists and five right wrists.

All arms were disarticulated proximally at the elbow junction and distally at the metacarpal-phalangeal joints. Soft tissues were removed preserving the interosseous membrane and the five tendons used in the investigation to simulate the grasp of an object: extensor carpi radialis longus (ECRL), abductor pollicis longus (APL), flexor carpi radialis

* Corresponding author at: Doctor Fleming 1, 6°G, 02400 Hellín, Albacete, Spain.
E-mail address: javilopezcot@gmail.com (J. López-Valenciano).

https://doi.org/10.1016/j.clinbiomech.2019.05.034
Received 21 February 2019; Accepted 30 May 2019

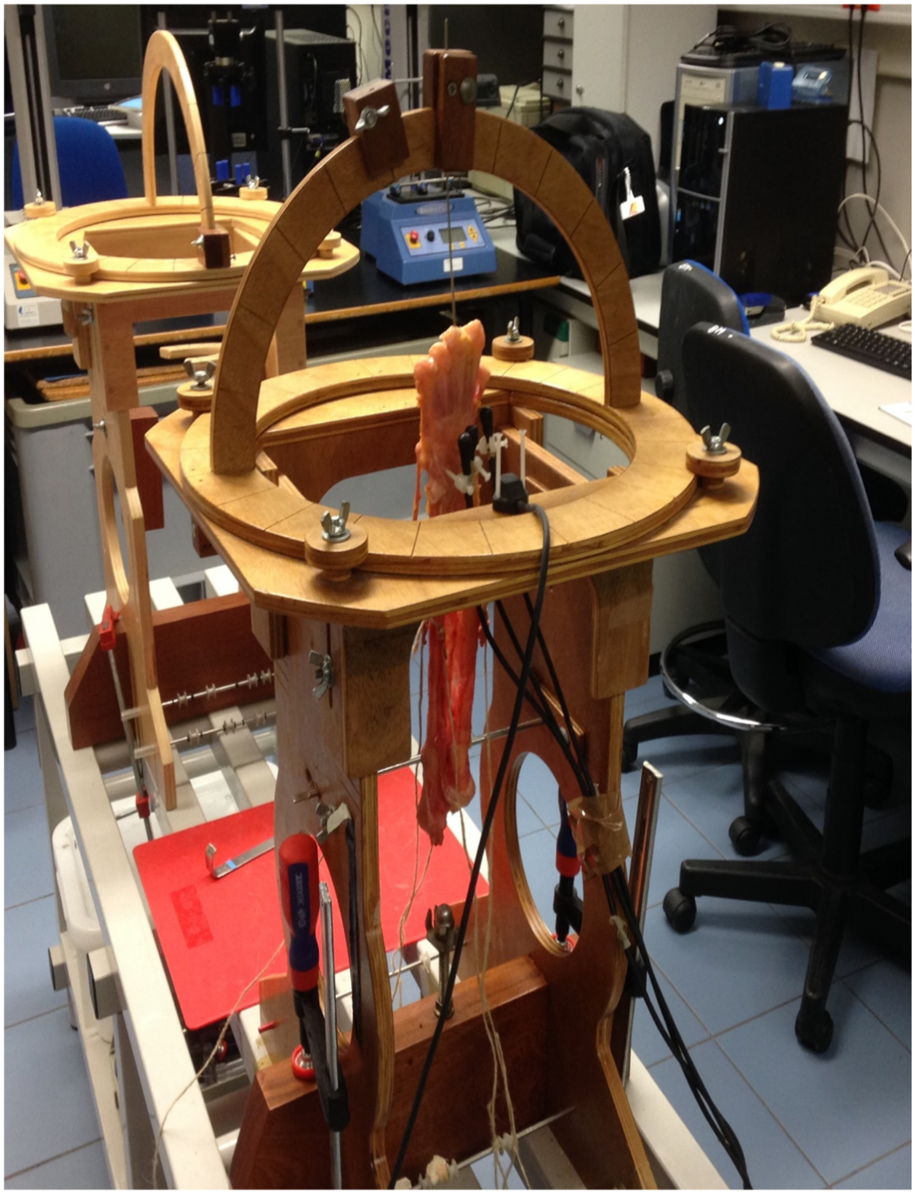

Fig 1. Experimental set-up with a forearm in the jig.

(FCR), extensor carpi ulnaris (ECU) and flexor carpi ulnaris (FCU). Special care was taken not to damage tendon retinacula. Specimens were set vertically in an arm holder specially designed for this type of investigation. They were fixed with two Steinmann pins drilled transversally through radius and ulna in neutral axial rotation. A pin was inserted vertically into the third metacarpal bone to control wrist position and was secured in a semi-circular frame over the jig (Fig. 1).

Changes in carpal bone rotation were monitored using the FASTRAK device (Polhemus FASTRAK sensors; Polhemus, Colchester, VT). This system generates an electromagnetic field in which rotations of moving sensors can be determined in six degrees of freedom. Three markers were fixed to the dorsal cortices of each of the scaphoid, the capitate and the triquetrum with nylon screws. The lunate was not directly measured since it followed the movement of the triquetrum. The radius was set as the *Z*-axis of reference. Rotation around the Z-axis (azimuth) indicated pronation-supination; rotation around the Y-axis (elevation) indicated flexion-extension; and rotation around the X-axis (rotation) indicated radial-ulnar deviation. Sensors operated at an update rate of 30 Hz and the system had a static accuracy of 0.8 mm and 0.15° for spatial orientation (Provided by the manufacturer).

The study was divided into two scenarios: initial wrist without lesions and wrist without scaphoid. In the first one, sensors were set in the scaphoid, capitate and triquetrum. In the second one, the same sensors were only set in the capitate and triquetrum. The selected tendons were connected with nylon strings to different amounts of weight depending on their own physiological cross-sectional area and their relative electromyographic activity when grasping an object with the wrist in neutral position (APL 9.8 N (1 kg), ECRL 24.5 N (2,5 kg), ECU 14.7 N (1.5 kg), FCR 13.7 N (1.4 kg), FCU 21.5 N (2.2 kg)) (An et al., 1985; Garcia-Elias, 1997; Kobayashi et al., 1997).

Before doing this, and in order to simulate the physiological muscle tone, all tendons were initially loaded with 1.5 N weight. Dart thrower movement axis were not directly analysed in this study.

After the first measurements, the scaphoid was removed, taking special care to avoid injury of the dorsal intercarpal ligament, the radio-triquetral ligament and the radio-scapho-capitate ligament. The same protocol was repeated, but without the scaphoid sensor. Orientation change of the capitate and the triquetrum was not measured prior to the loading.

Previous to the study we performed a sample size calculation with

Table 1
Effect of wrist loading before and after excising the scaphoid.

	Sup/Pro capitate	Flex/Ext capitate	Uln/Rad capitate	Sup/Pro triquetrum	Flex/Ext triquetrum	Uln/Rad triquetrum
Initial	Supination 10/12 2.95° SD 3.84°	Flexion 11/12 -3.24° SD 2.23°	Ulnar 11/12 -1.80° SD 1.96°	Pronation 6/12 -0.85° SD 3.80°	Flexion 12/12 -4.71° SD 2.84°	Ulnar 8/12 -0.85° SD 2.01°
Without scaphoid	Pronation 8/12 -0.70° SD 2.20° **p = 0.01**	Flexion 11/12 -3.86° SD 3.20° **p = 0.73**	Radial 9/12 0.75° SD 1.06° **p = 0.001**	Supination 9/12 0.70° SD 1.89° **p = 0.92**	Extension 7/12 0.69° SD 3.42° **p = 0.003**	Radial 9/12 1.84° SD 2.08° **p = 0.27**

All data represent the mean direction of rotation of the bones in all planes, cases that rotated to that position, mean and standard deviation. Sup/Pro plane: Positive means supination; Flex/Ext plane: Positive means extension; Uln/Rad Plane: Positive means radial deviation. Data in bold are statistically significant. SD: standard deviation.

an 80% statistic power and a 95% confidence level, needing at least ten specimens. Differences in angle rotations of the capitate and triquetrum were statistically analysed using the Wilcoxon test and $p < 0.05$ was considered statistically significant.

3. RESULTS

Wrists with scaphoidectomy presented many differences in comparison to intact wrists concerning the spatial rotation of capitate and triquetrum (Table 1). The capitate changed from supination (10/12) to pronation (8/12) ($p = 0.01$), and from ulnar deviation (11/12) to radial deviation (9/12) ($p = 0.001$) (Table 2). However, there were no differences in the flexion/extension plane presenting flexion in both of them.

Rotation of the triquetrum changed in all of the planes, moving from pronation- flexion and ulnar deviation to supination-extension and radial deviation. All these changes showed statistical significant differences (Fig. 2).

4. DISCUSSION

Wrist osteoarthritis is usually classified according to the etiological factor that triggered the degenerative process. The scaphoid is involved in most such cases, either in the form of scapholunate instability (Watson and Ballet, 1984) or scaphoid nonunion or malunion (Vender et al., 1987). Frequently, the bone is severely deformed by joint degeneration, or fragmented by trauma or avascular necrosis. In such circumstances, complete excision of the bone plus some sort of midcarpal stabilization procedure, most often the so-called "four-corner" arthrodesis, is the method most frequently recommended. Distal and proximal partial scaphoidectomies have also been described. The first is used as a treatment for scapho-trapezo-trapezoid osteoarthritis, scaphoid nonunion or associated with radio-scapho-lunate arthrodesis, to improve the range of movement (Marc Garcia-Elias et al., 2005). Proximal scaphoid resection has been recommended for the treatment of proximal scaphoid fractures or avascular necrosis when other procedures have failed (Markiewitz and Stern, 2005).

Total scaphoidectomy was occasionally performed in cases of scaphoid nonunion or scapholunate instability until the 60's. (Dwyer, 1949).

Most patients having undergone that procedure were dissatisfied with their poor clinical outcome, presenting pain, stiffness and severe radiological changes. Dorsal intercalated segment instability (DISI) and carpal collapse were consistently found in all of them (Ferreres et al.,

Table 2
All subjects data.

	Scaphoid			Capitate						Triquetrum					
	Initial			Initial			Without scaphoid			Initial			Without scaphoid		
	Sup/Pro	Flex/Ext	Uln/Rad	Sup/Pro	Flex/Ext	Uln/Rad	Sup/Pro	Flex/Ext	Uln/Rad	Sup/Pro	Flex/Ext	Uln/Rad	Sup/Pro	Flex/Ext	Uln/Rad
1	-0.09°	-2.26°	-0.49°	5.82°	0.26°	-4.14°	-1.62°	-0.99°	-0.29°	-2.76°	-0.96°	2.55°	0.75°	-2.08°	-0.88°
2	1.54°	-2.90°	-0.13°	2.24°	-2.99°	-2.49°	2.04°	-12.16°	1.41°	-10.59°	-4.86°	0.48°	-2.83°	-0.61°	-0.84°
3	1.28°	-5.86°	-1.78°	2.00°	-3.24°	-1.71°	-3.45°	-3.15°	0.48°	-4.71°	-6.17°	-1.49°	-0.67°	-2.07°	4.95°
4	-1.86°	-10.53°	-2.47°	-5.10°	-6.50°	-2.68°	-1.81°	-5.95°	1.19°	2.85°	-4.61°	-2.46°	0.06°	-3.79°	3.72°
5	1.82°	-8.82°	-4.45°	4.98°	-2.08°	-2.32°	-0.10°	-4.58°	0.60°	-0.18°	-9.64°	-3.92°	1.75°	0.78°	2.61°
6	2.22°	-5.04°	-1.62°	2.43°	-4.75°	-3.53°	2.23°	-4.64°	-0.09°	0.32°	-3.56°	-2.83°	2.36°	4.55°	-0.80°
7	-1.36°	-3.18°	0.06°	-0.40°	-5.31°	-1.75°	-3.20°	0.31°	0.90°	-1.26°	-2.80°	-0.34°	-2.63°	-1.66°	0.30°
8	-0.65°	-6.92°	0.84°	0.73°	-4.03°	-0.85°	-2.69°	-2.74°	1.11°	0.10°	-5.49°	0.93°	2.64°	2.92°	2.96°
9	3.14°	-4.03°	-1.95°	5.44°	-4.92°	-3.08°	-0.95°	-0.99°	-1.65°	1.79°	-4.71°	-1.00°	0.75°	5.68°	2.18°
10	-0.70°	-1.54°	-0.71°	1.20°	-0.38°	-0.07°	3.21°	-2.66°	2.47°	-0.12°	-0.82°	-0.63°	1.98°	-0.91°	0.78°
11	-0.32°	-9.78°	-2.64°	6.19°	-4.82°	-2.29°	-0.22°	-4.99°	1.29°	3.46°	-9.74°	-3.12°	2.27°	-1.17°	4.45°
12	4.82°	0.03°	4.60°	9.85°	-0.12°	3.34°	-1.83°	-3.78°	1.63°	0.91°	-3.18°	1.60°	2.01°	6.61°	2.61°
Negative	6	11	9	2	11	11	8	11	3	6	12	8	3	7	3
Positive	6	1	3	10	1	1	4	1	9	6	0	4	9	5	9
Mean	0.82°	-5.07°	-0.89°	2.95°	-3.24°	-1.80°	-0.70°	-3.86°	0.75°	-0.85°	-4.71°	-0.85°	0.70°	0.69°	1.84°
Standard error of the mean	0.57°	0.98°	0.65°	1.11°	0.64°	0.57°	0.63°	0.92°	0.31°	1.10°	0.82°	0.58°	0.55°	0.99°	0.60°
Median	0.59°	-4.53°	-1.16°	2.33°	-3.64°	-2.31°	-1.29°	-3.47°	1.01°	-0.01°	-4.66°	-0.81°	1.25°	-0.76°	2.40°
Standard deviation	1.99°	3.38°	2.25°	3.84°	2.23°	1.96°	2.20°	3.20°	1.06°	3.80°	2.84°	2.01°	1.89°	3.42°	2.08°
Variance	3.96°	11.44°	5.05°	14.76°	4.97°	3.84°	4.84°	10.25°	1.13°	14.47°	8.08°	4.03°	3.57°	11.68°	4.33°
Range	6.68°	10.56°	9.05°	14.95°	6.76°	7.48°	6.67°	12.47°	4.12°	14.05°	8.92°	6.47°	5.47°	10.40°	5.83°
Minimum	-1.86°	-10.53°	-4.45°	-5.10°	-6.50°	-4.14°	-3.45°	-12.16°	-1.65°	-10.59°	-9.74°	-3.92°	-2.83°	-3.79°	-0.88°
Maximum	4.82°	0.03°	4.60°	9.85°	0.26°	3.34°	3.21°	0.31°	2.47°	3.46°	-0.82°	2.55°	2.64°	6.61°	4.95°

All subjects data. In the table are represented every bone before and after removing scaphoid bone with their statistical values. Sup/Pro plane: Positive means supination; Flex/Ext plane: Positive means extension; Uln/Rad Plane: Positive means radial deviation.

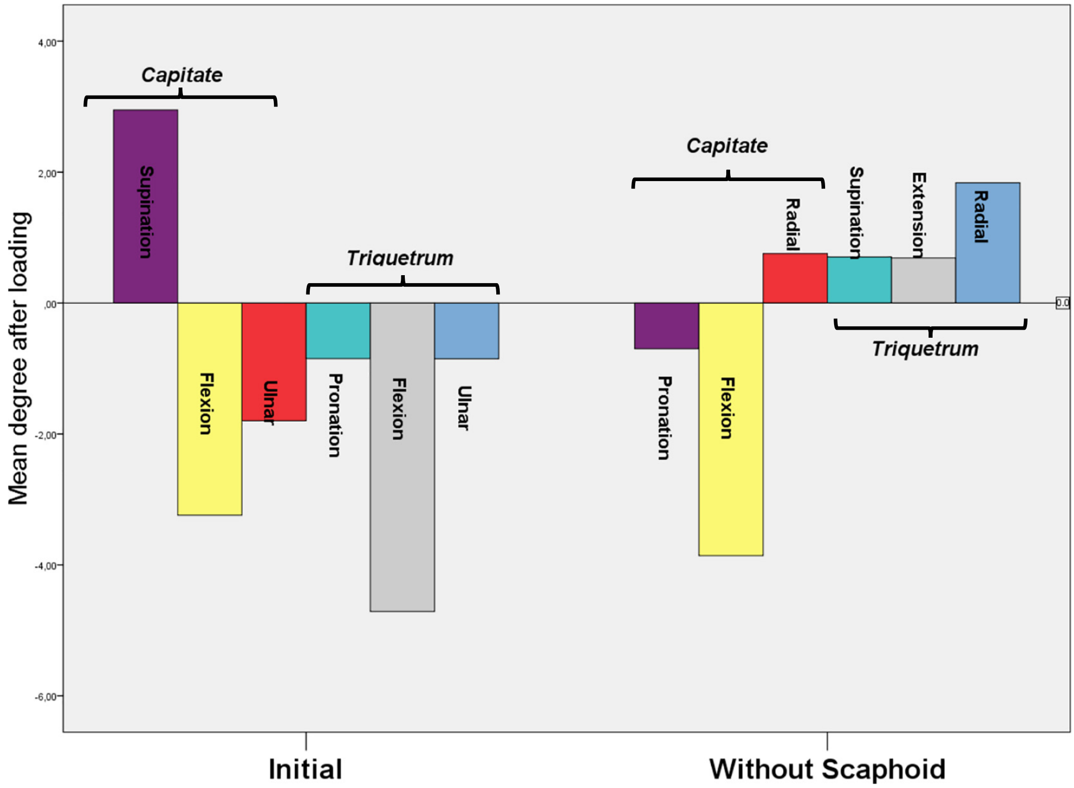

Fig 2. Movements of the carpal bones in the intact wrists and after excising the scaphoid. Supination, extension and radial deviation are positive values.

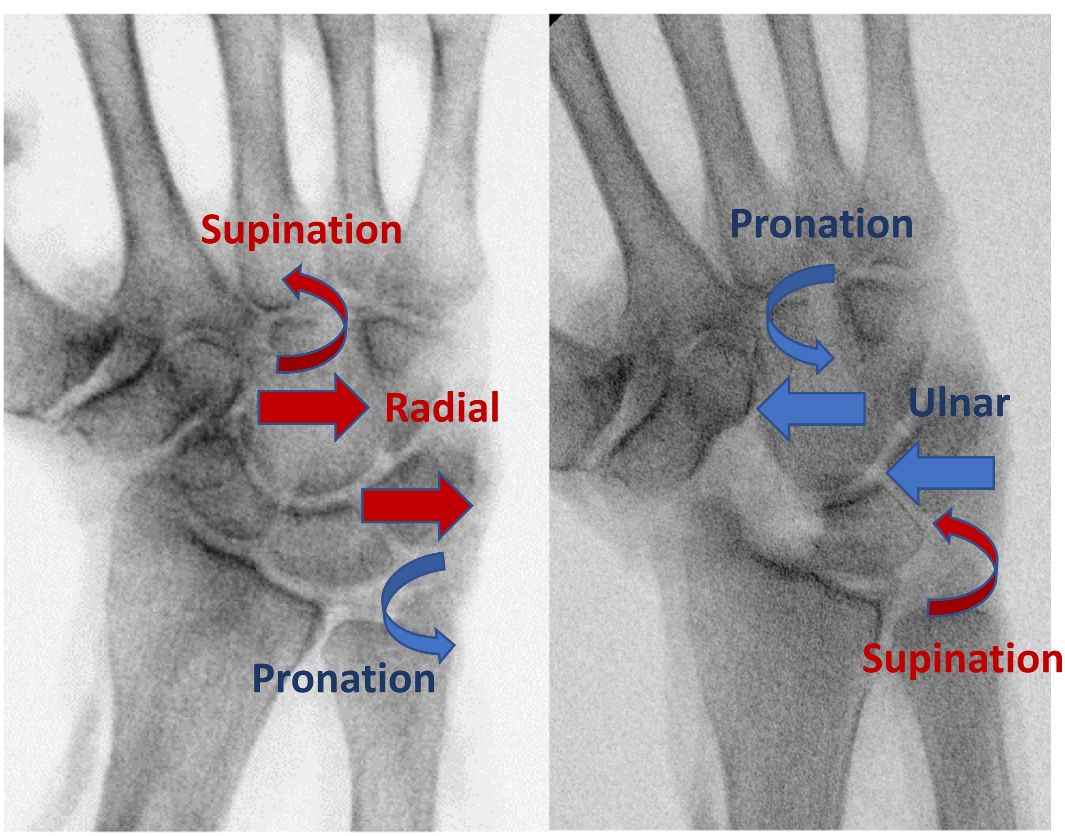

Fig 3. Fluoroscopy of an intact left wrist in radial deviation and after excising the scaphoid. Both bones change from radial to ulnar deviation. Capitate changes from supination to pronation, at the same time triquetrum changes from pronation to supination.

2009; Marcuzzi et al., 2012). Therefore, total resection of the scaphoid as an isolated procedure was abandoned. More recently, when a scaphoid resection has to be performed, it is standard practice to add a four corner arthrodesis in order to stabilize the rest of the carpal bones and change the load transmission to the radius (Mulford et al., 2009).

Although there is clinical awareness of the deleterious effects of isolated scaphoidectomies, to our knowledge, no biomechanical investigations of these effects have been conducted so far. In the absence of the scaphoid, the capitate and the triquetrum rotate in a different direction than a healthy wrist. Capitate changes from supination and ulnar deviation to pronation and radial deviation. At the same time we found that triquetrum changes from pronation-flexion and ulnar deviation to supination-extension and radial deviation. All these differences were statistically significant in our study.

When the scaphoid is removed and loads are applied to the wrist, radial collapse of the carpal bones is observed, adopting radial deviation (Fig. 3). In the intact wrist, the capitate transfers part of the load to the scaphoid and the scaphoid usually acts as a stop to it, but when the scaphoid is not present, the capitate migrates to a radial position. As the radial column is not present, the ulnar column is also under increased relative load, forcing the triquetrum to extend, just like a wrist being loaded on the ulnar side (Kauer, 1980; Kauer, 1986; Weber, 1984).

All the results observed in our study (DISI, radial collapse of the carpal bones and flexion of the capitate) correlate with the clinical outcome published in the literature (Ferreres et al., 2009; Marcuzzi et al., 2012). These results demonstrate that isolated scaphoidectomy is not recommended without additional stabilization in the rest of the carpal bones because of the deleterious effects on the wrist biomechanics.

Funding

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

Ethical approval

The authors certify that their institutions approved the human specimens handling protocol for this investigation, and that all investigations were conducted in conformity with ethical principles of Anatomical research.

Declaration of Competing Interest

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

References

An, K.N., Chao, E.Y., Cooney, W.P., Linscheid, R.L., 1985. Forces in the normal and abnormal hand. J. Orthop. Res. 3, 202–211.
Dwyer, F.C., 1949. Excision of the carpal scaphoid for ununited fracture. J. Bone Joint Surg. Br. 31B, 572–577.
Ferreres, A, Garcia-Elias, M., Plaza, R., 2009. Long-term results of lunocapitate arthrodesis with scaphoid excision for SLAC and SNAC wrists. J. Hand Surg. Eur. Vol. 34, 603–608.
Foumani, M., Strackee, S.D., Jonges, R., Blankevoort, L., Zwinderman, A H., Carelsen, B., Streekstra, G.J. In-vivo three-dimensional carpal bone kinematics during flexion-extension and radio-ulnar deviation of the wrist: Dynamic motion versus step-wise static wrist positions. J. Biomech. 2009, 42: 2664–71.
Garcia-Elias, M, 1997. Kinetic analysis of carpal stability during grip. Hand Clin 13, 151–158.
Garcia-Elias, M., Lluch, A., Ferreres, A., Papini-Zorli, I., Rahimtoola, Z.O., 2005. Treatment of radiocarpal degenerative osteoarthritis by radioscapholunate arthrodesis and distal scaphoidectomy. J. Hand Surg. Am. 30, 8–15.
Kauer, J.M., 1980. Functional anatomy of the wrist. Clin. Orthop. Relat. Res. 9–20.
Kauer, J.M., 1986. The mechanism of the carpal joint. Clin. Orthop. Relat. Res. 16–26.
Kobayashi, M., Garcia-Elias, M., Nagy, L., Ritt, M.J.P.F., An, K.N., Cooney, W.P., Linscheid, R.L., 1997. Axial loading induces rotation of the proximal carpal row bones around unique screw-displacement axes. J. Biomech. 30, 8–10.
Li, G., Rowen, B., Tokunaga, D., Ryu, J., Kato, H., Kihira, M., 1991. Carpal kinematics of lunotriquetral dissociations. Biomed. Sci. Instrum. 27, 273–281.
Marcuzzi, A., Lando, M., Sartini, S., Petit, A., 2012. Scaphoidectomy (instead of trapezectomy) in the treatment of rhizoarthrosis. Report of a case. Chir. Main. 31, 30–33.
Markiewitz, A.D., Stern, P.J., 2005. Current Perspectives in the Management of Scaphoid Nonunions. Instr Cour Lect 54, 99–113.
Mayfield, J.K., 1980. Mechanism of carpal injuries. Clin. Orthop. Relat. Res. 45–54.
Mayfield, J.K., Johnson, R.P., Kilcoyne, R.K., 1980. Carpal dislocations: pathomechanics and progressive perilunar instability. J. Hand Surg. Am. 5, 226–241.
Mulford, J.S., Ceulemans, L.J., Nam, D., Axelrod, T.S., 2009. Proximal Row carpectomy vs Four Corner Fusion for scapholunate (SLAC) or Scaphoid Nonunion Advanced Collapse (SNAC) Wrists: A Systematic Review of Outcomes. J. Hand Surg. Eur 34, 256–263.
Palmer, A.K., Werner, F.W., Murphy, D., Glisson, R., 1985. Functional wrist motion: a biomechanical study. J. Hand Surg. Am. 10, 39–46.
Ruby, L.K., Stinson, J., Belsky, M.R., 1985. The natural history of scaphoid non-union. A review of fifty-five cases. J. Bone Joint Surg. Am. 67, 428–432.
Ruby, L.K., Cooney, W.P., An, K.N., Linscheid, R.L., Chao, E.Y.S., 1988. Relative motion of selected carpal bones: A kinematic analysis of the normal wrist. J. Hand Surg. Am. 13, 1–10.
Salva-coll, G., Garcia-elias, M., Hagert, E., 2013. Scapholunate Instability: Proprioception and Neuromuscular Control. J. Wrist Surg. 1, 136–140.
Short, W.H., Werner, F.W., Fortino, M.D., Palmer, A.K., Mann, K.A., 1995. A dynamic biomechanical study of scapholunate ligament sectioning. J. Hand Surg. Am. 20, 986–999.
Vender, M.I., Watson, H.K., Wiener, B.D., Black, D.M., 1987. Degenerative change in symptomatic scaphoid nonunion. J. Hand Surg. Am. 12, 514–519.
Watson, H.K., Ballet, F.L., 1984. The SLAC wrist: scapholunate advanced collapse pattern of degenerative arthritis. J. Hand Surg. Am. 9, 358–365.
Weber, E.R., 1984. Concepts governing the rotational shift of the intercalated segment of the carpus. Orthop. Clin. North Am. 15, 193–207.