Stage III Advanced Wrist Collapse Treatment Options: A Cadaveric Study

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Abstract

Background Scapholunate advanced collapse and scaphoid nonunion advanced collapse result in high morbidity and pose significant challenges for active patients. Multiple treatment options have been proposed to yield satisfactory results; however, restoration of physiological wrist motion remains an issue.

Questions/Purposes The objective of this study was to compare wrist mobility after four different treatment methods for grade III wrist collapse: (1) no treatment, (2) scaphoidectomy and lunate-capitate arthrodesis, (3) scaphoidectomy, lunate-capitate arthrodesis, and triquetrum-hamate arthrodesis, and (4) scaphoidectomy, lunate-capitate arthrodesis, and triquetrum excision.

Methods Four paired ($n = 8$) fresh-frozen human cadaveric upper limbs were used in this controlled laboratory study. Computed tomography scans were collected at all testing states and measurements were made to evaluate midcarpal joint mobility and alignment.

Results A significant decrease in wrist extension was observed for all treatments. Middle column and two-column arthrodesis demonstrated no significant differences for carpal alignment and mobility. No significant differences were observed for triquetrum-hamate mobility or wrist extension between the partial and two-column arthrodesis. Triquetrum excision significantly improved ulnar deviation.

Conclusion The most important finding of this study was that the one-column arthrodesis has comparable carpal alignment and range of motion to that of bi-column arthrodesis.

Clinical Relevance The results of this study suggest that a stage III advanced wrist collapse can be treated by isolated lunate-capitate arthrodesis with scaphoidectomy. Fusion between the remaining carpal bones may not be necessary because the carpal alignment and range of motion of the remaining joints were not significantly different in the present study.

Keywords

- scaphoid nonunion advanced collapse
- arthritis
- advanced collapse
- biomechanics
- wrist

Altered wrist biomechanics consequent to a scapholunate dissociation or a scaphoid nonunion accelerates the degeneration of the surrounding articular surfaces and often induces arthritic progression referred to as a scapholunate advanced collapse (SLAC) or scaphoid nonunion advanced collapse (SNAC).^{1,2}

Watson and Ballet described four stages of the arthritic progression of the affected articulations.² Stage III progression is determined by radiological evidence of degenerative changes to both the radioscapoid and the lunate-capitate joint surfaces, and is generally associated with progressive pain and reduced wrist

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movement. Although treatment options for these pathologies have been described in the literature, restoration of physiological wrist motion poses a significant challenge in young and highly active patients.³

Traditionally, a scaphoidectomy and a midcarpal joint arthrodesis are performed to restore carpal alignment and maintain adequate range of motion. However, there is currently no consensus regarding the type of arthrodesis that should be performed. The most commonly performed technique is the bi-column³ or four-corner arthrodesis⁴ with scaphoidectomy, which entails fusion of the lunate, capitate, hamate, and triquetrum and excision of the scaphoid. Four-corner arthrodesis procedures have been reported to yield high union rates with low complication rates and only partial loss of wrist mobility.^{4–7} However, this surgery entails longer operative times, a bigger exposure, and consequently greater soft tissue damage. Partial arthrodesis of the lunate-capitate is another common procedure, initially proposed to preserve wrist mobility with a stable midcarpal fusion.³ Although early reports demonstrated inferior results when compared with four-corner arthrodesis,^{8,9} recent studies using advanced fixation techniques have reported good to excellent results for union rate, grip strength, and wrist mobility.^{10–12}

Lunate-capitate arthrodesis is generally performed with scaphoidectomy and can be performed with or without triquetrum excision. Triquetrum excision has been reported to improve outcomes for patients treated with partial arthrodesis.^{10,12} Biomechanically, triquetrum excision can better restore ulnar deviation of the wrist,¹³ decrease the risk of ulnar-carpal impingement, and allows for easier lunate reduction.¹² However, this procedure may decrease wrist stability due to the high density of proprioception receptors in the ligaments that converge into the triquetrum dorsally.¹³

Although clinical studies have compared various osteosynthesis methods, limited literature exists comparing the resultant midcarpal joint mobility of commonly used techniques in a biomechanical model. Therefore, the objective of this study was to compare the range of motion between different carpal bones after four different treatment methods for grade III SLAC or SNAC using cadaveric wrist specimens: (1) no treatment, (2) scaphoidectomy and lunate-capitate arthrodesis, (3) scaphoidectomy, lunate-capitate arthrodesis, and triquetrum-hamate arthrodesis, and (4) scaphoidectomy, lunate-capitate arthrodesis, and triquetrum excision. We hypothesize that the one-column arthrodesis (lunate-capitate fusion) will result in comparable carpal alignment and wrist range of motion to a bi-column arthrodesis (lunate-capitate-triquetrum-hamate fusion).

Materials and Methods

Specimen Preparation

Four paired ($n = 8$) fresh-frozen human cadaveric upper limbs with no prior injury or gross anatomic abnormality (mean age: 67.9 years, range: 49–64 years; all male) were included in this controlled laboratory study. Internal review board approval was not required to conduct this investigation because de-identified cadaveric specimens are exempt from review at our institution. Specimens were kept frozen

Fig. 1 Intramedullary nails mounted in a static support fixture.

at -20°C and thawed at room temperature 24 hours prior to testing. Forearms were cut 10 cm distal to the elbow. All soft tissues on the radius and ulna within 10 cm of the joint line were preserved. A custom mounting system was built to hold intramedullary nails that were fixed longitudinally through the radius and ulna ($\rightarrow$ Fig. 1).

The flexor and extensor compartments were carefully dissected to avoid damage to the extensor retinaculum. The extensor carpi radialis longus and brevis, the extensor carpi ulnaris, and the flexor carpi radialis and ulnaris were identified and the proximal 5 cm of each tendon was whipstitched with 2.0 Vicryl sutures.

To establish a neutral position of the wrist, a physiological load of 22 N was applied to each tendon measured by a dynamometer (Quantrol, Weight-Tronix Inc., Fairmont, MN) as described by Nanavati et al.¹⁴ To position the wrist in flexion, extension, radial deviation, and ulnar deviation, a 40-N force was applied to the corresponding tendons using a dynamometer. This method allowed for controlled and reproducible positioning of each specimen.

Surgical Technique

All surgical procedures were performed by a single upper limb orthopedic surgeon (A.M.). Steps of the surgery were as follows.

Scaphoidectomy and Lunate-Capitate Arthrodesis

The scaphoid was carefully resected from the dorsus, leaving the intercarpal dorsal and ulnar-triquetrum dorsal ligaments. The extensor retinaculum was transected 0.5 cm distal to the third dorsal compartment for better visualization of the lunate's proximal facet. The wrist was held in maximum flexion with radiography used to verify that the lunate-capitate joint was in neutral position and that the capitate head fully was covered by the lunate. A 1.2-mm Kirschner pin was placed in the lunate and progressed to the capitate, guided by radiographic visualization. A 2.1-mm-diameter drill was used to ream from proximal to distal, and a 3×36 mm ASNIS Micro screw (Stryker, Kalamazoo, MI) was inserted below the proximal articular cartilage of the lunate ($\rightarrow$ Fig. 2).

Triquetrum-Hamate Arthrodesis

A 5-mm incision was made in the capsule immediately distal to the ulnar styloid process and adjacent to the middle portion of the triquetrum. Under direct vision and with the

Fig. 2 Cadaveric images demonstrating (A) an intact lunate-capitate joint and (B) the wrist during lunocapitate arthrodesis.

wrist held in maximum flexion, a pin was placed in the midportion of the triquetrum, and under radiographic guidance the pin was progressed from the ulnar aspect of the triquetrum through the proximal corner of the hamate. A cannulated drill bit was used to ream a tunnel through the triquetrum and hamate, and then a 3 × 36 mm ASNIS Micro screw (Stryker) was inserted to fix the arthrodesis.

Triquetrum Excision

The ulnar column screw was removed from the triquetrum-hamate fusion and then the triquetrum was carefully resected with a scalpel through a dorsal incision without damaging the surrounding anatomy.

Imaging Evaluation

Computed tomography (CT) scans were performed using high-resolution equipment (Phillips Ingenuity Core 128 [Eindhoven, the Netherlands], axial slice thickness of 0.9 mm, spacing between slices of 0.45 mm, 120 kV, 201 mAs). Scans were collected of each specimen in neutral, flexion, extension, radial, and ulnar deviation before and after each surgical procedure was performed ([1] scaphoidectomy and lunate-capitate arthrodesis, [2] addition of triquetrum-hamate arthrodesis, and [3] triquetrum excision). CT scans were reconstructed in both coronal and sagittal planes. All reference lines, distances, and angles were created using the CT imaging software (Brilliance iCT version 3.2). The following measurements were recorded:

Ulnar-Triquetrum Distance

The distance of the ulnar-triquetrum joint space was measured on a 20-mm thick volumetric reconstruction coronal CT slice using maximum intensity projection (MIP). A line was drawn at the distal ulna, spanning the middle 50% of the joint surface (►Fig. 3; line A). From the most radial aspect of this line, another line was projected to the most proximal aspect of the triquetrum (►Fig. 3; line B), and this distance was recorded in millimeters as the ulnar-triquetrum joint space.

Radial-Lunate-Capitate Angle

The angle formed between the radius, lunate, and capitate was measured on a 20-mm thick coronal CT slice using MIP. A line

was drawn through the center of the radial shaft (►Fig. 4; line A) intersecting two lines drawn to the midpoints of the metaphyseal and diaphyseal regions of the radius (►Fig. 4; line B). Another line was drawn through the lunate and capitate (►Fig. 4; line C) intersecting the centers of each bone, represented by two previously drawn midpoint lines (►Fig. 4; line D). The angle formed between lines A and C was measured and recorded as the radial-lunate-capitate angle (►Fig. 4).

Lunate-Capitate Angle

The angle created between the lunate and capitate was measured on an 8-mm thick sagittal CT slice using MIP. A transverse line was drawn spanning the anterior and posterior distal aspects of the lunate (►Fig. 5; line A), and a perpendicular line was drawn originating from the midpoint (►Fig. 5; line B). Another line was drawn along the

Fig. 3 Computed tomography coronal view of a right wrist demonstrating the ulnar-carpal distance.

Fig. 4 Computed tomography coronal view of a right wrist demonstrating the radial-lunate-capitate angle.

major axis of the capitate (►Fig. 5; line C) for which two lines were previously drawn at the proximal and distal extremes (►Fig. 5; line D). The angle formed between lines B and C was measured and recorded as the lunate-capitate angle (►Fig. 5).

Radial-Lunate Angle

The angle found between the radius and lunate was measured on an 8-mm thick sagittal plane CT slice using MIP. First, two lines were drawn to the midpoints of the radial metaphysis and diaphysis (►Fig. 6; line B). Next, a line was drawn intersecting the midpoint lines through the center of the radial shaft (►Fig. 6; line A). A transverse line was drawn spanning the anterior and posterior distal aspects of the lunate (►Fig. 6; line C) and another line was drawn perpendicular through the midpoint of line C (►Fig. 6; line D). The angle formed between lines A and D was measured and recorded as the radial-lunate angle (►Fig. 6).

Triquetrum-Hamate Angle

The angle between the triquetrum and hamate was measured on an 8-mm thick sagittal plane CT slice using MIP. A transverse line spanning the anterior and posterior distal aspects of the triquetrum was created (►Fig. 7; line A) and then a perpendicular line was constructed, originating at the midpoint of line A (►Fig. 7; line B). A reference line was drawn through the center of the hamate, proximal to the base of the hamate hook (►Fig. 7; line D) and another was created along the major axis of the hamate (►Fig. 7; line C) through the midpoint of line D. The angle formed between lines B and C was measured and recorded as the triquetrum-hamate angle (►Fig. 7).

Fig. 5 Computed tomography sagittal view demonstrating the lunate-capitate angle.

Measurement of Observer Agreement

Three independent imaging trained examiners performed all measurements. Each observer was blinded to the others' readings. Interobserver reliability showed almost perfect agreement for the measurements, with a kappa value of 0.89.¹⁵

Statistical Analysis

One-way analysis of variance tests were performed to determine whether there were significant differences in the mobility of the wrist and midcarpal joint between the three tested arthrodesis procedures. All variables showed compatible distribution with the normal according to the Shapiro-Wilk test. A post-hoc test was performed using the Bonferroni method to identify the groups that behaved different in comparisons.

Results

Dissection and Identification of the Wrist Tendons

Identification of the extensor carpi radialis longus and brevis, the extensor carpi ulnaris, and the flexor carpi radialis and ulnaris were successfully performed in each specimen. Integrity of the extensor retinaculum was verified in all cases.

Fixation Performance

There were no failures or breakages of the screws in any of the testing states. No bending or screw migration was observed throughout the study.

Range of Motion

By alternating the application of a 40-N force to the corresponding tendons, flexion, extension, radial deviation, and ulnar deviation could be successfully performed in all states.

Fig. 6 Sagittal view of a computed tomography image of a right wrist demonstrating the lunate-radial angle.

Fig. 7 Sagittal view of a computed tomography image of a right wrist demonstrating the triquetrum-hamate angle.

Of note, the isolated resection of the scaphoid resulted in a highly unstable wrist (mostly in radial and dorsal flexion) that was restored by the lunocapitate fusion.

The data obtained from the coronal plane measurements (►Fig. 8) are presented in ►Table 1.

In the coronal plane, we observed the following: (1) the angles obtained from the radial deviation postoperatively were not significantly different ($p = 0.352$); (2) the ulnar deviation did not show significant changes after arthrodesis ($p = 0.978$); however, significant differences were observed following triquetrum excision ($p = 0.004$); and (3) the distance between the carpus and the triquetrum did

not result in a significant variation ($p = 0.986$) between the control and the various arthrodesis situations (one or two columns).

The data obtained from the measurements made in the sagittal plane (►Fig. 9) are presented in ►Table 2.

In the sagittal plane measurements, a decrease in wrist extension was observed throughout all groups ($p = 0.03$). No significant difference was found with respect to triquetrum-hamate mobility in flexion or extension ($p = 0.98$ and 0.96 , respectively) when comparing the isolated lunate-capitate arthrodesis to the lunate-capitate arthrodesis associated with the triquetrum-hamate arthrodesis.

Fig. 8 Computed tomography coronal image sequence of a right wrist with measurements made for the (A) intact wrist, (B) scaphoidectomy and lunate-capitate arthrodesis, (C) scaphoidectomy, lunate-capitate arthrodesis, and triquetrum-hamate arthrodesis, and (D) scaphoidectomy, lunate-capitate arthrodesis, and triquetrum excision.

Table 1 Coronal plane measurements presented as means with standard deviations

Coronal	Radial-lunate-capitate angle (degrees)				Ulnar-triquetrum distance (mm)		
	Intact	LC	LC + TH	LC + TH + Tr	Intact	LC	LC + TH
Neutral	15.4 (1.09)	22 (1.65)	21.6 (1.46)	17.7 (1.16)	8.6 (0.4)	9.0 (0.71)	10.1 (0.97)
Ulnar deviation	21.1 (0.52)	19.6 (0.79)	18.9 (1.03)	26.5 (1.4)	4.2 (0.55)	4.1 (0.78)	3.9 (0.53)
Radial deviation	27.5 (1.58)	31.3 (0.74)	36.2 (1.72)	36.6 (2.03)	8.7 (1.05)	11.3 (0.74)	12.4 (1.02)

Abbreviations: LC, lunate-capitate arthrodesis; TH, triquetrum-hamate arthrodesis; Tr, triquetrum excision.

Discussion

The most important finding of this study was that the one-column arthrodesis and the bi-column arthrodesis demonstrated comparable biomechanical results for carpal alignment and range of motion. No significant differences were found in triquetrum-hamate mobility when performing an isolated middle column arthrodesis or in association with ulnar column arthrodesis. The presented results suggest that wrist extension was the most affected movement by a midcarpal arthrodesis, yet no significant difference was observed between the two techniques. After triquetrum excision, there were no significant differences among the measured wrist movements other than ulnar deviation, which was significantly improved.

Prior to the advent of the four-corner arthrodesis for the treatment of stage III advanced collapsed wrist, it was reported that isolated fixation of the middle column (lunate-capitate) was sufficient.^{3,9,16} Despite clinical studies reporting adequate outcomes regarding postoperative range of motion and grip strength,¹⁰ Kirschenbaum et al⁸ reported a nonunion incidence rate of 33%. However, their results were likely attributed to the precarious nature of the osteosynthesis material (pins). Later on, Watson and Ballet² proposed a

scaphoidectomy in conjunction with a four-corner arthrodesis to improve union rates by increasing the bone surface of the fusion. This procedure was introduced over two decades ago and is currently the gold-standard treatment for reconstruction¹⁷ because of its high reported success rate.⁴⁻⁶ The four-corner arthrodesis was not biomechanically tested for comparison in the present study. There is currently no consensus regarding the “center of rotation” of the wrist; however, most authors agree that if one exists, it will be found in the head of the capitate, for both palmar-dorsiflexion and radial-ulnar deviation. Therefore, in the procedures tested in the present study the “center of rotation” or the capitate is annulated. Moreover, to reinforce this concept, the distal carpal-row bones act as a functional unit and having the capitate fused makes the whole row stable.

Controversy exists over whether it is necessary to fuse four carpal bones to achieve satisfactory union rates, correct lunate-capitate alignment, and good clinical results.¹⁸ In 2007, Goubier and Teboul¹¹ introduced the usage of axial compression screws for fixing the lunate-capitate arthrodesis to achieve the desired stable consolidation. They concluded that their high incidence of complications prior to the introduction of screws was due to the use of Kirschner pins, which

Fig. 9 Computed tomography sagittal image of a right wrist demonstrating (A) the intact state, (B) lunocapitate arthrodesis, and (C) triquetrum-hamate arthrodesis.

Table 2 Sagittal plane measurements presented as means with standard deviations

Sagittal	Lunate-capitate angle (degrees)			Lunate-radius angle (degrees)			Triquetrum-hamate angle (degrees)		
	Intact	LC	LC + TH	Intact	LC	LC + TH	Intact	LC	LC + TH
Neutral	5.9 (0.052)	5.0 (0.27)	4.8 (1.22)	8.2 (1.7)	10.1 (2.27)	16.4 (1.38)	12.4 (2.74)	1.3 (0.15)	0.3 (0.17)
Flexion	27.9 (5.57)	5.6 (0.68)	2.8 (0.9)	35.1 (7.93)	66.8 (4.66)	76.6 (1.56)	27 (3.19)	14.3 (0.36)	13.9 (0.99)
Extension	31.5 (6.41)	3.7 (0.45)	4.2 (1.1)	47.9 (1.15)	38.6 (1.27)	36.4 (1.96)	27.3 (3.37)	13.4 (0.64)	13.8 (1.49)

Abbreviations: LC, lunate-capitate arthrodesis; TH, triquetrum-hamate arthrodesis.

did not allow for sufficient axial compression. They also compared this technique with the four-corner arthrodesis stabilized by the spider plate and reported that this implant does not generate adequate compression in the axis of the arthrodesis.

In 2009, Ferreres and colleagues¹ reported on 17 cases treated with lunate-capitate arthrodesis with an 8- to 12-year follow-up. Superior functional outcome scores were reported when compared with the four-corner arthrodesis. Interestingly, they found that the four-corner arthrodesis resulted in greater radial and ulnar deviation. They also reported on neurophysiological data and determined that the ligaments attached to the triquetrum contribute to proprioceptive innervation of the wrist. Therefore, they did not recommend triquetrum excision. The results of the present study provide support for the recommendation by Ferreres et al. When presented with a functional lunate-triquetrum ligament in the absence of triquetrum-pisiform osteoarthritis, triquetrum excision may be unwarranted and may therefore reduce potential proprioceptive disorders.¹ Although triquetrum excision enhanced ulnar deviation in the present study, the authors advise that this procedure be performed with caution because of the potentially detrimental neurophysiological implications.

While the bi-column arthrodesis has been advocated in the literature,¹⁹ fusion of a single column requires less surgical intervention and the triquetrum-hamate interface does not require debridement, realignment, or fixation.¹¹ Single-column fusion also requires less amount of graft, reduces operating time, and is generally perceived as a less technically demanding surgery.^{4,11}

The authors acknowledge some weaknesses of the present study such as being a cadaveric study in which only specific positions and the limited number of specimens that were analyzed. Also, advanced-stage wrist collapse was not present in our study sample. Moreover, inherent to a time-zero cadaveric study, the results of this study do not reflect bones arthrodesis effect on motion performance. However, strengths rely on the fact that one experienced hand and wrist surgeon performed all the procedures and the usage of an advanced imaging software allowed for precise measurements to be collected.

In conclusion, the results of this study suggest that a stage III advanced wrist collapse with isolated lunate-capitate arthrodesis may result in comparable results to bi-column

fusion. Fusion between the remaining carpal bones may not be necessary because the carpal alignment and range of motion of the remaining joints were not significantly different in the present study. Randomized controlled trials and more high-level outcomes studies are needed to directly compare one-column and two-column arthrodesis to determine the best treatment for grade III wrist collapse.

Note

Internal review board approval was not required to conduct this investigation because de-identified cadaveric specimens are exempt from review at our institution. This investigation was performed at the biomechanics laboratory at the Hopsital Británico de Buenos Aires, Buenos Aires, Argentina.

Conflict of Interest

None.

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