The Effects of Capitate Height Alteration on Dorsal Intercalated Segment Instability

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Abstract

Question/Purpose Carpal kinematics may be influenced by the manipulation of carpal dimensions. This may provide a surgical alternative to unpredictable soft tissue reconstruction for scapholunate dissociation. The purpose of this study was to determine if altering capitate height can correct dorsal intercalated segment instability (DISI).

Materials and Methods Five cadaveric wrists had baseline radiolunate (RL) angles and scapholunate (SL) intervals measured fluoroscopically, confirming no baseline DISI. We simulated open- and clenched-fist testing via a constant load of the wrist extensors and sequential loading of the digital flexors. We confirmed no baseline static/dynamic DISI. The SL ligament and secondary stabilizers (scapho-trapezio-trapezoid [STT] and dorsal intercarpal ligaments) were transected. Repeat loading and fluoroscopic measurements confirmed creation of static DISI. Capitate height was altered in three interventions: 2 mm shortening osteotomy of capitate waist, 7 mm shortening osteotomy of capitate waist, and 2 mm lengthening of original capitate height by insertion of a spacer at capitate waist. The osteotomized capitate was stabilized with a Kirschner wire; RL angles and SL intervals were measured via fluoroscopy during open- and clenched-fist testing. Primary and secondary outcomes were change in RL angle and SL interval, from the DISI stage to each capitate shortening and lengthening stage.

Results SL ligament and secondary stabilizers sectioning created a DISI pattern, with abnormal RL angles ($>15^\circ$) and widened SL intervals. Neither capitate shortening nor overexpansion corrected RL angles or SL intervals in any DISI-induced wrists.

Conclusions Under the conditions studied, isolated capitate shortening or lengthening did not correct radiographic DISI posturing of the lunate following sectioning of the SL and STT interosseous ligaments. Further study of carpal kinematics with more substantial bone changes and loading of adjacent joints may be beneficial.

Clinical relevance Surgeons performing capitate shortening osteotomy in isolation should not expect to improve DISI.

Keywords

- capitate shortening osteotomy
- dorsal intercalated segment instability
- scapholunate dissociation

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Can altering capitate height correct dorsal intercalated segment instability (DISI)?

Recent investigations have shown that correction of scapholunate dissociation (SLD) and associated DISI can be achieved with scaphoid lengthening. This finding was demonstrated in a cadaver model via insertion of a spacer at the level of the scaphoid waist to enlarge the scaphoid beyond its normal anatomic dimensions.¹ This suggests that carpal kinematics may be effectively influenced by manipulation of carpal dimensions and may present a surgical alternative to unpredictable soft tissue reconstructive procedures for SLD. The application of this concept clinically would require elective osteotomy of the intact scaphoid, with accompanied risk of nonunion. In contrast, the elective osteotomy of an alternate carpal bone, such as the capitate, may be more appealing if able to correct carpal instability. However, it should be noted that correction of lunate positioning alone in the absence of scaphoid stabilization in cases of SL instability may not necessarily resolve pain or improve function.

Several investigators have demonstrated that the axes of wrist flexion and extension pass through the head of the capitate²⁻⁴ and the long axis of the capitate will lie dorsal to that of the lunate and the radius whenever DISI is present.⁵ We hypothesized that capitate shortening could impact the lunate posture to correct DISI. Conversely, we also hypothesized that capitate lengthening would result in increased SL diastasis and lunate extension.

Using a biomechanical model similar to that employed for scaphoid lengthening by Capito et al,¹ the purpose of our study was to determine if changing the relative dimensions of the capitate could similarly correct carpal instability without SL ligament repair or reconstruction.

Materials and Methods

Five fresh never-frozen cadaveric upper extremity specimens were used. The specimens showed no SL injury or carpal instability based on initial physical and fluoroscopic evaluation. The biomechanical model for this study has been described in detail.^{1,6,7} Each specimen was stabilized on a stand with an external fixator. Weights were suspended from the dissected digital flexors (2.3 kg to the combined flexor digitorum superficialis and profundus tendon groups) and wrist extensors (2.8 kg to extensor carpi ulnaris and an additional 2.8 kg to the combined extensor carpi radialis longus and brevis) to simulate a functional power-grip clenched-fist in 20° of wrist extension confirmed with a goniometer (— Fig. 1). The weights were removed from the digital flexors to create the unloaded open-fist state. A subcutaneous 12.7-mm marker was used to calibrate fluoroscopic length measurements. Baseline radio-lunate (RL) angles and scapholunate (SL) intervals were measured. The RL angle was determined from the intersection of a line drawn perpendicular to the two distal poles of the lunate and another drawn parallel to the medullary canal of the radius on lateral imaging. The SL interval was measured as the distance between the midpoints of the scaphoid and lunate on true posteroanterior imaging.⁸ In this fashion, we confirmed none of the specimens had static or dynamic baseline carpal instability.

Fig. 1 Setup for biomechanical model for clenched-fist simulation. Weights are attached to the dissected digital flexors and wrist extensors to simulate a power-grip clenched-fist position. PA, posteroanterior.

The entire SL ligament and the scapho-trapezio-trapezoid (STT) and dorsal intercarpal (DIC) ligaments were resected through a dorsal open approach to create a DISI deformity, verified with repeat fluoroscopic RL angle and SL interval measurements. Capitate height was then altered in three sequential interventions:

1. 2 mm shortening osteotomy of the capitate waist
2. 7 mm shortening osteotomy of the capitate waist
3. 2 mm lengthening of the original capitate height by insertion of a spacer at the capitate waist

At each stage of capitate shortening or lengthening, the capitate was secured with a 1.6 mm smooth Kirschner wire (K-wire) and we again measured RL angles and SL intervals both in open- and clenched-fist loading positions via fluoroscopy. Via direct visualization, we ensured that the K-wire fixation was not directly influencing adjacent carpal bones throughout testing.

Our primary outcome was change in RL angle from the induced DISI position to that measured for each sequential capitate shortening and lengthening stage. Our secondary outcome was change in SL interval from the induced DISI position to that measured for each sequential capitate shortening and lengthening stage. The results were all tested for normality and equal variance and were assessed with one-way repeated measures analysis of variance for both open- and clenched-fist positions with a significance level set at $p = 0.05$.

Results

Sectioning of the SL ligament and secondary stabilizers successfully created DISI demonstrated by abnormal RL angles ($> 15^\circ$) (►Fig. 2) and widened SL intervals (►Figs. 3 and 4) compared with baseline in all wrists during clenched-fist testing ($p = 0.008$ with 80% power and $p = 0.05$ with 45% power, respectively). Without ligamentous repair, capitate shortening of 2 or 7 mm and capitate lengthening of 2 mm

all had no significant influence on RL angles or SL intervals in either open- or clenched-fist testing and thus did not correct the induced pattern of carpal instability. All RL angle data passed normality and equal variance tests, while the SL interval data failed normality and passed equal variance tests.

Discussion

There are multiple soft tissue surgical options for SLD and associated DISI to either repair, reconstruct, or augment the scapholunate ligament, including, but not limited to, tendon transfer reconstruction,⁹ modification of the Brunelli procedure using a three-ligament tenodesis,¹⁰ volar and dorsal limb reconstruction,¹¹ dorsal capsulodesis,¹² and other modifications of Blatt's technique.¹³ In contrast, there are currently no elective bony procedures used clinically to correct SLD and DISI while preserving baseline wrist motion.

A serendipitous finding of scaphoid lengthening using the medial femoral trochlea (MFT) flap for osteochondral reconstruction of proximal pole scaphoid nonunion was that it also corrected SLD and DISI.¹⁴ In that series of 16 consecutive cases of scaphoid nonunion reconstructed with the MFT flap, at 14 months average follow-up, there was no progressive worsening in SL angle or DISI despite near-total resection of the SL ligament as part of the procedure.¹⁴ The authors theorized that this might be due to the creation of a scaphoid

Fig. 2 Radiolunate angles of capitate shortening and overstuffing. The shortening and overstuffing procedures did not correct scapholunate dissociation in the clenched view radiographs (radiolunate angle $> 15^\circ$). $p > 0.05$ (neutral vs. clenched) for native and 5 mm shortening groups. $p < 0.05$ for transected, 2 mm shortening, and overstuffed groups. Error bars show standard deviation. SL, scapholunate.

Fig. 3 Radiographs showing the effects of capitate shortening osteotomy and overstuffing on the scapholunate interval. All radiographs depict the clenched-fist model. Transecting the SL ligament and secondary stabilizers successfully created instability as shown by SL widening in the bottom left panel. The interval remained widened with both 2 and 5mm shortening osteotomy and 2 mm overexpansion. PA, posteroanterior; SL, scapholunate.

Fig. 4 Scapholunate ligament intervals for capitate shortening and overstuffing procedures. All $p < 0.05$ (neutral vs. clenched) for each treatment group, aside from the overexpansion model where $p = 0.09$. SL interval > 3 mm for neutral and clenched positions in the overexpansion model. Error bars show standard deviation. SL, scapholunate.

that is larger than its native dimensions. Capito et al subsequently tested that hypothesis in a cadaveric clenched-fist model.¹ They first successfully created SLD and DISI by sectioning the SL ligament and the surrounding secondary stabilizers (STT and DIC ligaments). They then effectively lengthened the scaphoid by inserting sawbone wafers into an osteotomy in the scaphoid waist, fixing the construct with a K-wire and retesting the clenched-fist model. Their correction of the RL angles in this model confirmed the hypothesis that scaphoid lengthening can influence carpal alignment.

There are some limitations to our study. Radiographic measurements do not capture all aspects of carpal kinematics nor do they evaluate altered carpal contact pressures. The ligament sectioning procedure may have altered other carpal kinematics in other unforeseen ways. Capitate shortening and lengthening may also have altered other intercarpal loading that was not assessed. Our study may also have been unable to detect a significant difference in degree of SLD and DISI before and after changing capitate dimensions when one may actually exist (Type II error). This seems unlikely, as we observed no tendency for any meaningful change in the instability patterns while performing the capitate length changes or during testing.

An osseous shortening or lengthening procedure to correct carpal instability patterns is appealing. Such an intervention could provide a more predictable and reliable means of addressing DISI, as compared with the soft tissue procedures currently available. However, scaphoid lengthening via an elective osteotomy poses an inherent concern for nonunion. While nonunion is also a potential risk for capitate osteotomy, this has not been observed to be a clinically significant problem likely due to a more robust vascularity compared with the scaphoid. Capitate shortening has had clinical success for early Kienböck disease.^{15,16} In a cadaver study, capitate shortening resulted in a decrease in RL contact pressure by 53%, while radioscapoid joint pressure increased by 39%.¹⁷ These results and the biomechanics of the carpus present the possibility that altering capitate height could impact SLD and DISI. Unfortunately, using the same biomechanical testing model of Capito et al,¹ our study indicates that neither capitate shortening nor lengthening to the levels studied here impacts SLD and DISI.

To potentially correct or prevent carpal instabilities, altering other carpal bone dimensions, such as with combined capitate and hamate shortening, may deserve further study. Other methods to shift the capitate's axis of rotation, such as a dorsal opening wedge osteotomy or volar translation of the proximal capitate, may warrant further investigation as well.

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Conflict of Interest

None declared.

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