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# Biomechanical Properties of First Dorsal Extensor Compartment Regarding Adequacy as a Bone-Ligament-Bone Graft

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**Background:** Bone-ligament-bone grafts for reconstruction of the scapholunate ligament are a valuable tool to prevent disease progression to carpal collapse. Locally available grafts do not require an additional donor site. The first extensor compartment was evaluated biomechanically regarding its possible use as an autograft.

**Methods:** Twelve native fresh-frozen, human cadaver specimens were tested by applying axial tension in a Zwick Roell machine. Load to failure, transplant elongation, and bony avulsion were recorded. The load to failure was quantitated in newtons (N) and the displacement in length (millimeters). Parameters were set at distinct points as start of tension, 1 mm stretch and 1.5 mm dissociation, failure and complete tear, and were evaluated under magnified visual control. Although actual failure occurred at higher tension, functional failure was defined at a stretch of 1.5 mm.

**Results:** Mean load at 1 mm elongation was 44.1 ± 28 N and at 1.5 mm elongation 57.5 ± 42 N. Failure occurred at 111 ± 83.1 N. No avulsion of the bony insertion was observed. Half the transplants failed in the central part of the ligament, while the rest failed near the insertion but not at the insertion itself. Analysis of tension strength displayed a wide range from 3.8 to 83.7 N/mm at a mean of 33.4 ± 28.4 N/mm.

**Conclusions:** The biomechanical tensile properties of the first dorsal extensor compartment are similar to those of the dorsal part of the scapholunate ligament. A transplant with a larger bone stock and a longer ligament may display an advantage, as insertion is possible in the dorsal, easily accessible part of the carpal bones rather than in the arête-like region adjacent to the insertion of the scapholunate ligament. In this study, 1.5 mm lengthening of the bone–ligament–bone transplant was defined as clinical failure, as such elongation will cause severe gapping and is considered as failure of the transplant. *(Plast Reconstr Surg Glob Open 2017;5:e1397; doi: 10.1097/GOX.0000000000001397; Published online 26 July 2017.)*

## BACKGROUND

Scapholunate dissociation is the most common, and if untreated, a serious form of carpal instability.[1] This injury often occurs in young, active patients and warrants special attention. Rotatory subluxation of the scaphoid will cause consecutive degenerative changes of the wrist. As long as no degenerative changes in the carpal bones are present, the best treatment would be anatomic reduction and reconstruction of the ligament. As direct repair is only possible within a limited timeframe, results are often disappointing.[2,3] Even in fresh injuries, reconstruction algorithms for chronic instabilities may be used, as due to the orientation of dorsal fibers the scapholunate (SL) ligament does not hold stitches well. Methods of ligament augmentation originate partially in poor healing potential between the interosseous ligament and the surface of the scaphoid. Treatment of chronic, dissociative, scapholunate ligament injuries is controversial. Most authors agree that the 2 main goals of reconstruction include correction of the dorsal intercalated segment instability (DISI)

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deformity and the reconstruction of the ligament itself. Various procedures, including direct ligament repair with capsular augmentation, tendinoplasties, transplants, and dorsal capsulodesis have been advocated.[4–10] However, few of these methods restore normal anatomy or function. The SL ligament consists of dorsal, proximal, and palmar units, while the dorsal aspect is mechanically most important.[11–15] SL dissociation often displays a rupture of all units. In such cases, a stable reconstruction of all parts of the ligament at its insertion points seems most desirable. Most autografts described only reconstruct the dorsal unit, as it is considered crucial with regard to biomechanical stability and kinematics.

Theoretically, a bone-ligament-bone graft between the scaphoid and the lunate could result in a proper realignment of the carpus and should prevent carpal collapse and ultimately posttraumatic osteoarthritis.[16] Dorsal retinacular replacement of the scapholunate ligament has had some clinical success. This replacement has been recently tested biomechanically and was found to be significantly weaker than the ligament it aims to replace.[17] Ligament transplants from the foot require a distant donor site at the lower extremity with added donor-site morbidity.[18,19] Thus, such techniques have not gained widespread popularity. The preferred donor site for harvest is the hand and wrist. Numerous grafts have been described and used.[20–22] Besides tensile strength similar to that of the native ligament, an ideal graft should provide features for stable anchoring of the transplant to the scaphoid and lunate. Especially, shorter transplants with smaller portions of bone may prove too unreliable to anchor with a single screw in the scaphoid and the lunate, while other anchoring options may not exist. Dislocated screws and thus transplants are a common sequela. Therefore, a longer transplant, bridging the dorsal gap, and allowing inset in a trough could be advantageous. The goal of this study was the evaluation of a potential BLB graft, which is easily accessible, can be harvested in variable width, and with variable bone stock without significant donor-site morbidity. The region of the first extensor compartment is well known to hand surgeons (Fig. 1). When releasing the first extensor compartment, the very robust ligament with its wide bony insertion can be accessed easily and be used as a graft (Figs. 2, 3). The aim of this study was to evaluate its biomechanical stability and thus suggesting an easily accessible and versatile option for BLB reconstruction.

## METHODS

Twelve native fresh-frozen, human cadaver specimens were tested (3 males, 3 females, 6 right arms, 6 left arms). The biomechanical analysis did not require approval of the ethical committee. Prior to testing, differently fixed cadavers had been evaluated. Fixed cadaver specimens did not display comparable mechanical properties. In some cases, a more than 3-fold load than in fresh cadavers had to be applied and failure of the transplants occurred later. In further tests with fresh cadavers, different settings to attach the bony insertion were tested and screw fixation was deemed unusable since screws gave way well before ligament failure. The best option for fixation was a mechanism consisting of two 5-mm steel pins squeezing the bony insertion as increasing force was applied. Cadavers selected as specimens had no radiological or physical evidence of wrist deformities, carpal fractures, or dislocations or signs

**Fig. 1.** First dorsal compartment before harvesting; skin and subcutaneous tissue have been removed.

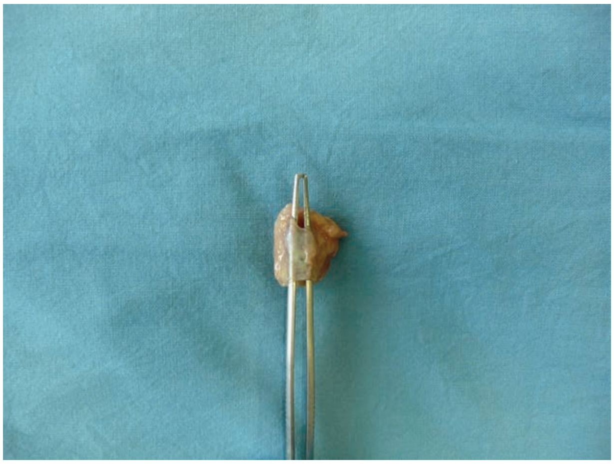

**Fig. 2.** Harvested graft, forceps within the canal.

**Fig. 3.** Possible orientation as press fit.

of previous wrist and hand surgery. Specimens were stored at -20 °C until thawing at room temperature for 24 hours before preparation and testing. Soft tissue, including tendons, was carefully removed, and the first dorsal extensor compartment was harvested in a width of 4 mm with a cubical bone stock of 10 × 10 mm). Testing was completed in 1 day, and each specimen was used as its own control.

Biomechanical testing by applying axial tension was performed with a Zwick/Roell testing machine (Z020, Zwick/Roell, Ulm, Germany; Fig. 4). The specimens were rigidly mounted with custom-made steel holders in the upper part of the testing apparatus. One holder each secured the bony insertion on both sides.

The testing protocol included a preload of 1 N with further load to failure at a constant rate of 5 mm/min. Load, relative changes of transplant length, tear of bony insertion were digitally registered. To control and correlate changes in the length of the transplant, a metric scale under direct magnified visual inspection was placed next to the transplant indicating ligament failure.

The load to failure was quantitated in newtons (N), and the displacement in length (mm). Parameters were set at distinct points as start of tension, 1 mm and 1.5 mm elongation, failure and complete tear, and were evaluated under magnified visual control (Fig. 5). Although actual failure occurred at higher tension, functional failure was estimated at an elongation of 1.5 mm, as further dissociation will clinically cause gapping and consecutive rotatory subluxation, leading to scapholunate advanced collapse wrist.

**Fig. 4.** Zwick Roell machine, experimental set-up.

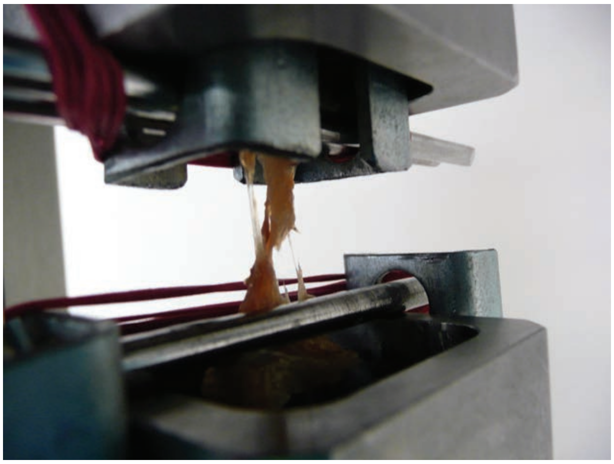

**Fig. 5.** Complete failure in the central portion of the ligament.

Data of biomechanical experiments were filtered at 50 Hz and continuously stored using TestXpert II (Zwick/Roell, Ulm, Germany). Data were analyzed using SPSS (SPSS GmbH Software, Munich, Germany, Version 11.5.1) software. Correlation analysis was performed with Spearman'S Rho. A $P$ value < 0.05 was considered statistically significant.

## RESULTS

The average width of the first extensor compartment was 9 mm with an SD of 2 mm and length at the internal portion of the extensor compartment was 13 ± 0.1 mm. The strength testing results are provided in Table 1 and Figure 6. After being mounted into the device and macroscopically stretched, an average of 0.7 mm stretch had to be administered before tension became apparent. Mean force at 1 mm stretch was 44.1 ± 28 N and at 1.5 mm stretch 57.5 ± 42 N. Failure occurred at 111 N. No avulsion of the bony insertion was observed. Half of the transplants failed in the central portion of the ligament, while the others failed near the insertion but not at the insertion itself. The analysis of tensile strength by load versus displacement graph (N/mm) showed mean values of 33.4 ± 28.4 N/mm at a range of 3.8–83.7 N/mm (Tables 2, 3; Fig. 7). Tension strength displayed a positive correlation with load to failure (Spearman-Rho for tension strength at 1 mm, 0.938; $P = 0.000007$; at 1.5 mm, 0.883; $P = 0.000014$).

## DISCUSSION

Several options for BLB transplants exist and are in clinical use.[23,24] The biomechanical properties of the first dorsal extensor compartment are comparable to those of the dorsal part of the SL ligament.[19]

With a mean tension strength of 33.4 ± 28.4 N/mm, specimens tested in the actual investigation displayed a high range of 3.8–83.7 N/mm, indicating a high interindi-

**Table 1. Force**

| Force 1 mm (N) | Force 1.5 mm (N) |
|---|---|
| 44.1 | 57.5 |

>Force at 1 and 1.5mm.

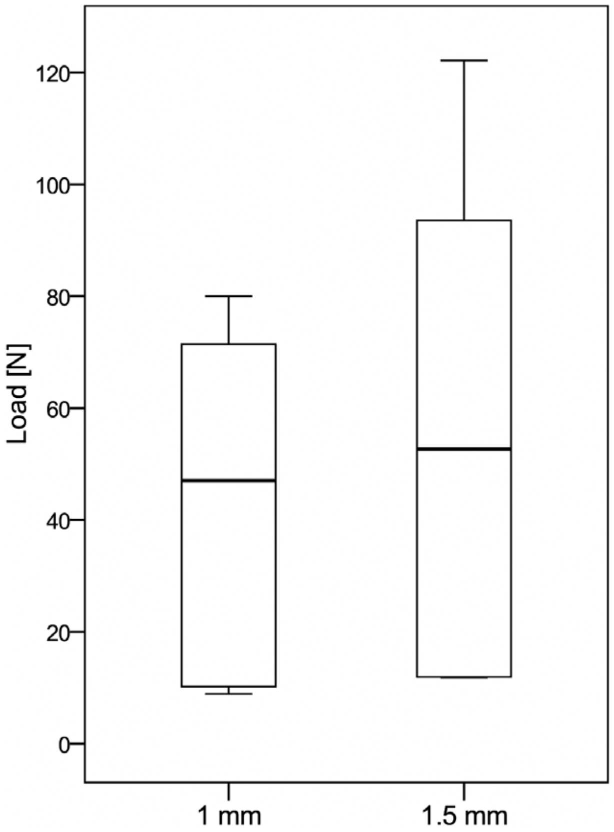

**Fig. 6.** Load; load at 1 mm and 1.5 mm.

**Table 2. Slope**

| | Average | Range | | Average | Range |
|---|---|---|---|---|---|
| Slope X1 | 0.8 | 0.1–1.6 | Slope Y1 | 23.1 | 2.6–52.9 |
| Slope X2 | 2.1 | 0.8–2.6 | Slope Y2 | 68.2 | 7.8–219.8 |
| Difference | 1.3 | | Difference | 45.1 | |
| Inclination | 33.4 | | | | |

Inclination in degrees.

**Table 3. Slope Values**

| | Average | Range |
|---|---|---|
| X max | 5.7 | 2.6–10 |
| X failure | 4.3 | 2.7–7.3 |
| Y max | 120.4 | 34.4–255.3 |
| Y failure | 111.1 | 18.6–255.3 |

Failure at 1.5mm, max representing biomechanical failure.

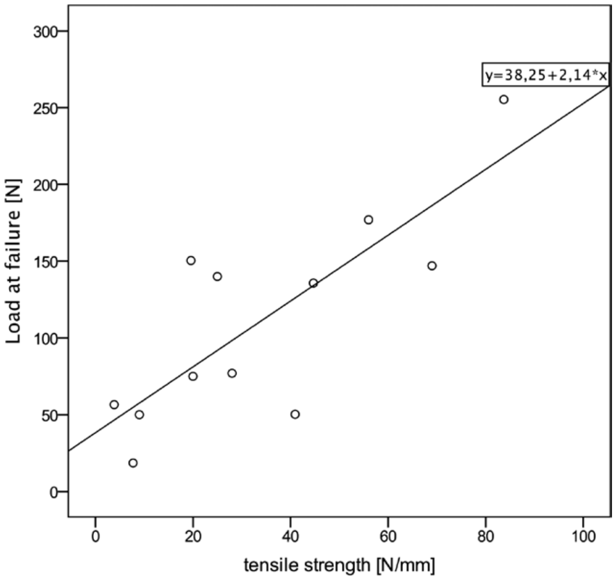

**Fig. 7.** Tensile strength; load at failure (N), tensile strength (N/mm).

vidual variability and quality of the compounds, indicated also by the positive correlation for tensile strength with load to failure. Thus, delicate extensor compartments displayed low tensile strength.

Harvesting the BLB transplant from the same extremity, eliminating a distant second donor site, is regarded as advantageous by most surgeons. While the carpometacarpal region is a good donor site, transplants may display limited amount of bone stock, thus impairing or even preventing solid anchoring to the scaphoid and lunate, respectively. A transplant with a solid, larger bone stock and a longer ligament may improve the possibilities for anchoring in the dorsal, easily accessible, bony surfaces rather than in the arête-like region bordering the SL ligament. A true press fit anchoring with a 90° orientation to the vector of the SL ligament additionally securing the BLB transplant against sliding can be obtained, which reduces the sole reliance on screw fixation. The tested ligaments displayed a strength resembling the strength of the dorsal SL ligament, as described by other authors.[19] Clinical failure was defined in our study as a lengthening of 1.5 mm. Although true failure occurred at considerably higher forces, this definition of failure is clinically justified in our opinion. Considering the physiological SL distance is about 2 mm and correction of DISI deformity hardly ever restores anatomical conditions, a larger than normal postoperative SL distance is regularly seen, which may also be the result of the Mayfield paradoxon.[1] SL distance of more than 2 mm will eventually cause rotatory causing degenerative changes. We defined more than 1.5 mm lengthening of the BLB transplant as clinical failure, opposed to biomechanical failure, as such lengthening will most obviously result in a clinical presentation of more than 4 mm gapping, which is normally regarded as failure. This phenomenon is important, as biomechanical properties with respect to failure of transplant may be largely overestimated in clinical use, as transplants may lengthen and thus become insufficient before failure may be seen in the laboratory. As seen in our data, the strength of the transplant deteriorates after lengthening of more than 1.5 mm. Failure of the transplant never occurred as a tear but always as progressive elongation. As space within the wrist is confined, SL gapping may naturally not exceed 10 mm, although no ligament may be present. Therefore, elongation beyond a certain level must be regarded as clinical failure as rotational deformity cannot be prevented any more. Although mechanically stronger transplants are known, it is not to be concluded that clinical failure is solely directly correlated to the strength of the transplant itself.[18,19] Clinical success also depends on anchoring and thus subsequent healing and vascularization. Consecutively "easier to handle" BLB transplants warrant attention. The tested autograft has the theoretical advantage of having 2 large bone stocks, allowing bone-to-bone healing on a large surface rather than tendon-to-bone healing, which may be less predictable. Opposed to carpometacarpal transplants, the increased length of the transplant allows anchoring further away from the SL gap, thus easing technical difficulties. Another advantage may lie in the freedom of placing the graft, choosing press fit and anchoring screws perpendicular to pull of the ligament instead of often 45 degrees in CMC grafts. The donor site for the autograft is locally available and convenient.

## CONCLUSIONS

The biomechanical tensile properties of the first dorsal extensor compartment are similar to those of the dorsal part of the SL ligament. A transplant with a larger bone stock and a longer ligament may display an advantage, as insertion is possible in the dorsal, easily accessible part of the carpal bones rather than in the arête-like region adjacent to the insertion of the SL ligament. In this study, 1.5 mm lengthening of the BLB transplant was defined as clinical failure, as such elongation will cause severe gapping and is considered as failure of the transplant. It is beyond the scope of the present article to describe indications, contraindications, and technique for the proposed autograft procedure based merely on biomechanical results. Clearly, further research needs to be conducted to obtain such necessary information. However, it may be appropriate to comment on the possible use as a ligament autograft. Based on these findings, the first dorsal extensor compartment has been used by the authors for various indications such as flexor tendon pulley reconstruction on a regular basis.

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