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HANDSURGERY

# Reconstruction of chronic scapholunate dissociation with the modified scapholunate axis method (SLAM)

**Juergen H. Dolderer[1,2] · Katja Zimny[1] · Silvan M. Klein[1] · Michael Koller[3] · Lukas Prantl[1] · Sebastian Geis[1]**

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## Abstract

**Introduction** Injury to the scapholunate (SL) ligament represents a common trauma of the wrist but is frequently misdiagnosed because of non-specific pain. Established methods for SL reconstruction mainly focus on reducing pain and maintaining the reposition result at the expense of mobility and strength. This study aimed at restoring stability and reducing pain while simultaneously maintaining mobility and strength using the scapholunate axis method (SLAM).

**Material and methods** 22 patients (19 male and 3 female) aged between 26 and 64 years with an SL ligament lesion underwent SLAM reconstruction. Mean duration between injury and operation was 7.9 ± 5 (1–24) months. Hand functions using DASH, Mayo Wrist Score, range of motion, pain (at rest and weight-bearing) and grip strength were assessed prior and 12 months postoperative. Additionally SL angle was collected pre- and postoperative.

**Results** Each of the 22 patients improved significantly postoperative in DASH and Mayo Wrist Score with regard to pain at rest and under weight-bearing. Additionally, grip strength could be improved up to 31% compared to preoperatively. In contrast, range of motion and SL angle and grip strength did not change essentially.

**Conclusions** The secondary SL ligament reconstruction technique SLAM shows promising results. Pain was significantly relieved and grip strength was significantly increased. Additionally, DASH and Mayo Wrist Score could be significantly improved. However, SL angle and range of motion could not be improved in every patient and plane.


**Keywords** SL dissociation · SL reconstruction · Scapholunate injury · SLAC wrist · Carpal collapse

## Introduction

Scapholunate (SL) ligament rupture represents a common trauma of the wrist and mainly affects young men in the middle of their active professional life. Injuries to the SL ligament may occur in isolation, for instance after a fall on the outstretched hand, or as a concomitant injury in the context of distal radius fractures [1–6]. If untreated, such injuries result in the displacement of the carpal ring system, an increase in the scapholunate interval, a dorsal tilt of the lunate, as well as palmar flexion of the scaphoid [7]. Garcia-Elias demonstrated in an in vivo four-dimensional study that when the SL ligaments are torn, the scaphoid shifted towards the radial styloid more than the lunate by dart-throwing motion exercises, creating an SL dissociation, which means that dart-throwing exercises put tensile power on the SL ligament [8, 9]. Changed biomechanical conditions inevitably lead to progressive arthritic changes [6, 10, 11] and subsequently to irreversible damage to the wrist [12]. At the advanced stages of the disease, patients complain about pain, restricted range of motion, as well as significantly reduced strength. For this reason, SL ligament injury is not only limiting for the affected patients but—owing to the age structure of these patients—also highly important from a socio-economic point of view.

In the acute phase, symptoms are often vague or the injury is overlooked because of more obvious concomitant injuries such as a distal radius fracture [2, 3, 6, 7, 11]. For this reason, secondary reconstruction methods are of particular importance. Despite these far-reaching

✉ Juergen H. Dolderer
drdolderer@hotmail.com

1 Department for Plastic, Hand and Reconstructive Surgery, University Medical Center Regensburg, Regensburg, Germany

2 Department for Plastic, Reconstructive, Aesthetic and Hand Surgery, Medical Center Bayreuth, Bayreuth, Germany

3 Department for Clinical Studies, University Medical Center Regensburg, Regensburg, Germany

consequences, there is still no gold standard treatment for chronic SL ligament injuries. Current surgical techniques are insufficient because they are mainly focused on restoring stability or securing the reduction result at the expense of mobility and strength.

Treatment modalities next to stabilizing interventions such as dorsal capsulodesis are reconstructive interventions (bone–ligament–bone grafting or tenodesis) and ablative treatments (four-corner arthrodesis or proximal row carpectomy). Dorsal capsulodesis [13] is particularly useful for mechanical support and aimed at preventing palmar flexion of the scaphoid bone. Pappou and colleagues [14] showed that strength may almost be fully restored after dorsal capsulodesis; however, mobility was significantly impaired after this type of intervention. Bone–ligament–bone grafts represent an exact substitute of the scapholunate ligament complex joining the lunate and the scaphoid [15]. Despite the promising results yielded in initial studies, long-term results showed a high rate of secondary implant failure due to insufficient bone ossification and secondary arthrosis.

SL ligament reconstruction by means of different tenodesis techniques aims at restoring the natural anatomical conditions of the ligamentous complex as accurately as possible. This type of treatment is aimed at achieving the best possible improvement in function, strength, range of motion, and the highest possible degree of freedom from symptoms. The most commonly used techniques are those established by Brunelli and Brunelli [16], Garcia Elias and colleagues [17], and van den Abeele and colleagues [18]. Here, the SL ligament is reconstructed with parts of the flexor carpi radialis tendon that is pulled through a tunnel in the distal scaphoid bone and fixed to either a bone or a ligament. These techniques guarantee high stability but result in reduced strength and limited range of motion in comparison to the contralateral hand [16–18].

Ablative treatments such as four-corner arthrodesis, proximal row carpectomy or radioscapholunate arthrodesis permanently fix structures to their position [12]. Ablative treatment only constitutes surgical repair that delays long-term damage; thus, ablative treatment is viewed as a one possible final treatment option because the range of motion of the wrist is significantly impaired after surgery, and some patients continue to have considerable pain [19–21].

The secondary reconstruction technique termed scapholunate axis method (SLAM) is aimed at ensuring the best possible anatomically correct axial reconstruction of the SL ligament and lifting strength, a high level of stability, and a sufficient range of motion. This study provides an insight into this surgical technique and its postoperative course [22, 23].

## Materials and methods

### Study design

Twenty-three consecutive patients were enrolled in this prospective study, One patient had to be excluded because he did not appear to the 12-month follow-up appointment. 19 male and 3 female of the remaining 22 patients have been operated using the modified SLAM technique due to an SLligament injury (Fig. 1a–d). Injury of the SL ligament was diagnosed using MRI. The mean age of the patients was 47.2 ± 10.6 (26–64) years. Seventeen patients were right handed and five patients were left handed. Thirteen operations were performed on the left hand and nine on the

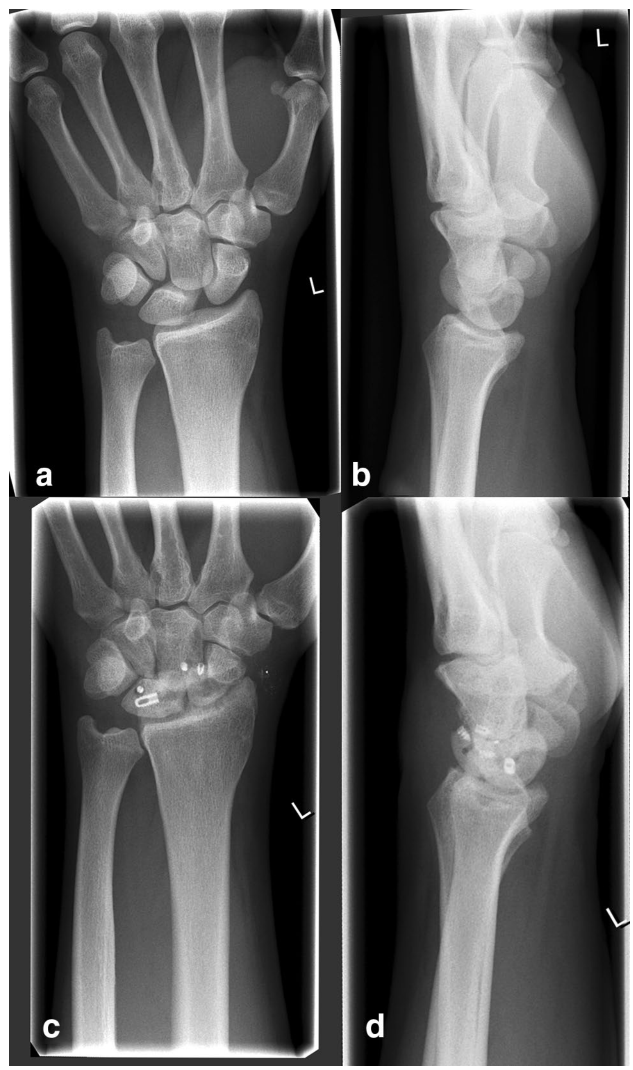


**Fig. 1** Conventional X-ray of a static SL ligament rupture. **a** Anterior–posterior view, preoperative. **b** Lateral view, preoperative. **c** Anterior–posterior view, 12 months postoperative. **d** Lateral view, 12 months postoperative

right hand. Mean duration between injury and operation was 7.9 ± 5 (1–24) months. Four patients performed light, ten moderate and eight heavy physical activity during their daily work.

Prior to surgery, an experienced hand surgeon assessed the range of motion, pain (by means of a visual analogue score, VAS), strength (using a dynamometer and by means of the grip), as well as the radiological parameter SL angle. In addition, wrist function was evaluated with objective questionnaires (the DASH and the Mayo Wrist Scores) 12 months after surgery.

All patients were informed about the study content and signed the information document as well as the informed consent form. The study was approved by the local ethics committee and conducted in accordance with the Declaration of Helsinki.

## Surgical technique

The operation was performed in accordance with the previously described technique of our group [24]. Briefly summarized, the surgery is conducted in supine position, with a bloodless environment, and using an optical magnifying glass. After harvesting the palmaris longus tendon or split flexor carpi radialis tendon, reduction of the scaphoid and lunatum was performed. The C-ring reduction guide is placed via an additional incision directly above the anatomical snuff box.

The positioning of the C-ring reduction guide is crucial for the operation. The pointed tip of reduction guide is placed on the proximal ulnar aspect of the lunate. The entry point for the Kirschner wire is on the radial facet of the scaphoid at the ridge of the cartilage bearing part. Flexion and ulnarduction facilitate correct placement of the reduction guide (Table 1).

After radiological control, the 1.6 mm Kirschner wire is placed. Subsequently, the pilot hole is drilled with a cannulated step drill. The tendon graft is inserted into the graft anchor (Arthrex, Naples, USA) and then hammered into the drill channel. The graft is fixed to the scaphoid bone with a PEEK tenodesis screw (Arthrex, Naples, USA) and the ends of the graft are fixed to the lunate and capitate bone with two separate bone anchors as a modification of the technique of Yao, thus preventing scapholunate dissociation as well as palmar tilt of the scaphoid bone. If the tendon graft is long enough, an additional bone anchor can be placed in the distal part of the scaphoid to augment the dorsal fixation between lunate and scaphoid. After the reduction procedure, 1.4–1.6 mm Kirschner wires are placed for scapholunar and scaphocapital transfixation (Fig. 2a–d). Postoperative immobilization in a cast enclosing the thumb is required for 6 weeks to secure the reconstruction result.

**Table 1** Patient data

| Patient | Sex | Age | Handedness | Injury site | Interval to operation (months) | Physical activity |
|---|---|---|---|---|---|---|
| 1 | Female | 55 | Left | Left | 13 | Light |
| 2 | Male | 43 | Left | Left | 6 | Light |
| 3 | Male | 30 | Right | Right | 9 | Heavy |
| 4 | Male | 53 | Right | Left | 6 | Heavy |
| 5 | Male | 55 | Right | Left | 6 | Light |
| 6 | Male | 26 | Right | Right | 12 | Heavy |
| 7 | Male | 42 | Right | Left | 0 | Moderate |
| 8 | Male | 45 | Right | Right | 6 | Moderate |
| 9 | Male | 42 | Right | Right | 4 | Moderate |
| 10 | Male | 59 | Right | Right | 6 | Heavy |
| 11 | Male | 64 | Right | Left | 13 | Moderate |
| 12 | Male | 53 | Right | Left | 11 | Heavy |
| 13 | Male | 37 | Right | Right | 8 | Moderate |
| 14 | Female | 36 | Right | Right | 7 | Heavy |
| 15 | Male | 57 | Left | Right | 3 | Moderate |
| 16 | Female | 36 | Right | Right | 8 | Moderate |
| 17 | Male | 38 | Right | Left | 5 | Light |
| 18 | Male | 60 | Right | Left | 5 | Moderate |
| 19 | Male | 55 | Left | Left | 12 | Moderate |
| 20 | Male | 60 | Right | Left | 4 | Heavy |
| 21 | Male | 48 | Left | Left | 5 | Heavy |
| 22 | male | 45 | Right | Left | 24 | Moderate |

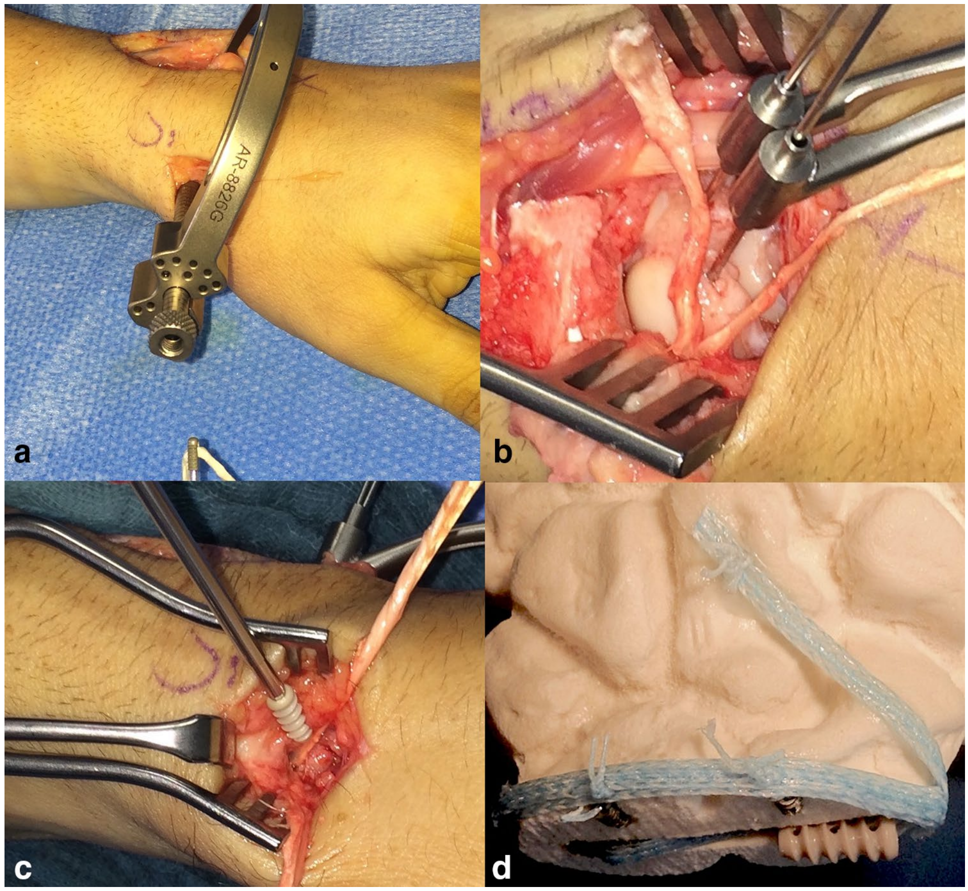


**Fig. 2** Individual operative steps of the SLAM technique. **a** Accurate placement of the drill guide. **b** Reposition of the scaphoid and the lunate. **c** Locking of the tendon transplant in the scaphoid using the tenodesis screw. **d** Schematic illustration of the modified SLAM technique

## Statistical analysis

Results are given as mean ± standard deviation. A paired *t* test was applied to analyze differences between preoperative and postoperative data. Statistical analysis was performed using SPSS statistical software package (SPSS 25 Inc., IL, USA). Values at $p < 0.05$ were considered as statistically significant.

## Results

The DASH and the Mayo Wrist Score were significantly improved from 78.4 ± 19.5 points before surgery to 48.1 ± 19.8 ($p < 0.001$) points 12 months after surgery (DASH) and from 32.3 ± 18.2 to 62.7 ± 16.6 ($p < 0.001$) points 12 months after surgery (Mayo).

Pain at rest measuring 2.1 ± 2.6 on the VAS before surgery was significantly reduced to 0.67 ± 1.5 ($p < 0.001$) 12 months after surgery and pain while weight-bearing from 5.8 ± 2.7 to 2.6 ± 2.6 ($p < 0.001$).

Total range of motion for extension/flexion was 101.0 before and after 12 months. The total range of motion for radialduction and ulnarduction was 44.4 before and 50.5 after 12 months. The total range of motion for pronation and supination was 167.3 before surgery and 177.1 12 months after surgery.

Grip strength was increased from 54.6 ± 28.9 kg before surgery to 70.4 ± 45.8 kg 12 months after surgery. However, it was not statistically significant ($p = 0.09$).

The SL angle could be improved straight after the operation; however, the reduction could not be maintained 12 months postoperatively: 75.6 ± 17.6 preoperatively and 76.6 ± 22.0 postoperatively ($p = 0.82$).

The results are displayed in detail in Table 2.

All patients were satisfied with the postoperative course and would choose this treatment option again if necessary.

## Discussion

Scapholunate ligament lesions represent the most common carpal ligament injury [25]; if untreated, such injuries result in severe arthritic changes [2, 7]. Because SL ligament injuries are often overlooked in the course of the initial trauma [2, 4], secondary reconstruction methods are all the more important. Despite no current technique can completely restore the kinematics of the wrist joint, a few selected

**Table 2** Results preoperative and 12 months postoperative

| Patient | Pain (at rest) | Pain (at rest) | Pain (weight-bearing) | Pain (weight-bearing) | DASH -Score | DASH -Score | Mayo Wrist Score | Mayo Wrist Score | Ext/flex | Ext/flex | Rad/uln | Rad/uln | Sup/pro | Sup/pro | SL angle | SL angle |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Preoperative | After 12 months | Preoperative | After 12 months | Preoperative | After 12 months | Preoperative | After 12 months | Preoperative | After 12 months | Preoperative | After 12 months | Preoperative | After 12 months | Preoperative | After 12 months |
| 1 | 4 | 2 | 8 | 8 | 96 | 75 | 20 | 40 | 70-0-60 | 60-0-40 | 25-0-40 | 20-0-30 | 80-0-90 | 90-0-90 | 84 | 76 |
| 2 | 0 | 0 | 2 | 0 | 39 | 35 | 80 | 80 | 70-0-80 | 30-0-30 | 20-0-45 | 20-0-25 | 90-0-90 | 90-0-90 | 90 | 91 |
| 3 | 0 | 0 | 3 | 0 | 53 | 25 | 60 | 80 | 70-0-70 | 70-0-70 | 30-0-40 | 20-0-45 | 90-0-90 | 90-0-90 | 86 | 98 |
| 4 | 3 | 0 | 7 | 2 | 76 | 44 | 35 | 70 | 20-0-30 | 70-0-55 | 5-0-5 | 10-0-45 | 50-0-50 | 90-0-90 | 62 | 55 |
| 5 | 4 | 0 | 6 | 0 | 83 | 32 | 35 | 45 | 60-0-50 | 60-0-50 | 20-0-30 | 20-0-30 | 90-0-90 | 90-0-90 | 86 | 92 |
| 6 | 8 | 5 | 8 | 8 | 55 | 68 | 30 | 30 | 20-0-50 | 40-0-35 | 10-0-30 | 10-0-20 | 90-0-90 | 90-0-90 | 63 | 64 |
| 7 | 0 | 0 | 0 | 1 | 70 | 34 | 35 | 60 | 60-0-60 | 40-0-40 | 10-0-30 | 20-0-40 | 90-0-90 | 90-0-90 | 88 | 120 |
| 8 | 0 | 0 | 3 | 0 | 98 | 50 | 10 | 75 | 70-0-70 | 70-0-75 | 10-0-40 | 20-0-40 | 60-0-90 | 90-0-90 | 60 | 60 |
| 9 | 0 | 0 | 8 | 2 | 78 | 28 | 35 | 70 | 60-0-60 | 45-0-40 | 10-0-30 | 20-0-30 | 90-0-90 | 70-0-85 | 90 | 100 |
| 10 | 4 | 0 | 7 | 4 | 105 | 48 | 40 | 75 | 30-0-25 | 40-0-30 | 15-0-20 | 15-0-35 | 90-0-90 | 90-0-90 | 97 | 98 |
| 11 | 3 | 0 | 6 | 3 | 105 | 31 | 45 | 70 | 55-0-45 | 50-0-60 | 10-0-20 | 20-0-45 | 85-0-85 | 90-0-90 | 43 | 86 |
| 12 | 2 | 3 | 6 | 6 | 90 | 74 | 45 | 30 | 50-0-40 | 40-0-30 | 10-0-20 | 10-0-20 | 90-0-90 | 70-0-90 | 98 | 59 |
| 13 | 0 | 0 | 1 | 1 | 82 | 50 | 50 | 50 | 30-0-40 | 60-0-50 | 15-0-15 | 10-0-30 | 50-0-90 | 80-0-90 | 67 | 82 |
| 14 | 0 | 0 | 6 | 0 | 51 | 36 | 45 | 85 | 60-0-60 | 50-0-60 | 20-0-30 | 30-0-40 | 90-0-90 | 75-0-90 | 50 | 52 |
| 15 | 4 | 0 | 4 | 2 | 88 | 82 | 5 | 60 | 40-0-10 | 50-0-40 | 20-0-30 | 10-0-30 | 90-0-90 | 90-0-90 | 70 | 71 |
| 16 | 3 | 0 | 8 | 1 | 49 | 38 | 40 | 70 | 70-0-30 | 50-0-35 | 5-0-20 | 10-0-30 | 20-0-90 | 90-0-90 | 57 | 52 |
| 17 | 0 | 0 | 8 | 4 | 82 | 25 | 15 | 85 | 70-0-65 | 75-0-65 | 30-0-40 | 20-0-30 | 90-0-90 | 90-0-90 | 82 | 86 |
| 18 | 3 | 0 | 7 | 2 | 83 | 87 | 20 | 55 | 60-0-20 | 65-0-40 | 10-0-30 | 30-0-10 | 80-0-80 | 90-0-90 | 47 | 30 |
| 19 | 0 | 0 | 9 | 3 | 75 | 71 | 20 | 45 | 50-0-55 | 50-0-50 | 10-0-30 | 40-0-25 | 90-0-90 | 90-0-90 | 92 | 57 |
| 20 | 0 | 0 | 4 | 1 | 68 | 66 | 20 | 65 | 45-0-45 | 50-0-55 | 10-0-30 | 15-0-35 | 90-0-90 | 90-0-90 | 95 | 91 |
| 21 | 0 | 0 | 3 | 3 | 92 | 47 | 15 | 65 | 50-0-65 | 40-0-50 | 25-0-40 | 20-0-40 | 90-0-90 | 90-0-90 | 73 | 83 |
| 22 | 8 | 4 | 10 | 6 | 107 | 30 | 10 | 75 | 40-0-40 | 55-0-55 | 20-0-20 | 10-0-35 | 80-0-80 | 90-0-90 | 87 | 86 |

procedures have been proven to be effective in addressing important symptoms of scapholunate dissociation. However, current methods for secondary SL reconstruction only warrant pain relief and stability at the expense of mobility and strength.

The aim of our study was to prove a reconstructive technique that achieves a very high possible level of both mobility and freedom from pain by restoring the natural anatomical conditions of the ligamentous complex as accurately as possible. The innovative nature of SLAM reconstruction is characterized by the multi-dimensional anatomical reconstruction of the SL ligament. In this reconstruction procedure, the palmaris longus tendon is pulled through a tunnel in the scaphoid bone and interlocked in the lunate bone, thus ensuring correct axial fixation of the two bones. Additionally, the ends of the graft are fixed to the lunate and capitate bone with two bone anchors. Such fixation prevents presumably more the dorsal inclination of the lunate and palmar dislocation of scaphoid bone, which may occur when using purely dorsal reconstruction methods. Destabilization of the wrist due to weakness of the flexor carpi radialis tendon may also be avoided. Fixation of the tendon graft to the capitate bone counteracts palmar tilting of the scaphoid bone, which represents a new feature of the method established by Yao [22].

Both DASH and Mayo Wrist Score were significantly improved 12 months postoperatively. The DASH score, in particular, could be reduced on an average by 30 points. Franchignoni and colleagues considered a reduction in the DASH score by 10–15 points clinically relevant [26].

The range of motion showed only slightly increased mobility in supination and pronation, as well as in radial–ulnarduction. Mobility in extension and flexion was not impaired due to surgery and was almost the same as before surgery. In contrast, other reconstruction methods have been associated with restricted range of motion after surgery. When taking the method of dorsal capsulodesis in isolation, long-term results have shown that SL dissociation is difficult to avoid [13, 14, 27–29]. SL ligament reconstruction with bone–ligament–bone grafts serves as the best possible substitute for the natural anatomical conditions of the scapholunate ligamentous complex. The studies by van Kampen and colleagues showed a promising postoperative range of motion; however, two thirds of the patients had developed arthritic changes over the course of time [15, 18, 30]. The tenodesis technique developed by Brunelli ensures a high degree of stability, but the wrist is also considerably restricted in flexion after surgery. Brunelli described reduced postoperative flexion of up to 60% [16]. For this reason, when modifying the tenodesis technique, Garcia-Elias and Abeele omitted fixation via the radio-carpal joint. The study by Abeele and colleagues showed significantly reduced pain but still restricted postoperative range of motion [16–18].

Scapho-trapezio-trapezoid arthrodesis as an alternative method has been used. However, the carpal kinematics have been altered as the scaphoid bone is linked to the distal carpal row. Studies over a longer period have shown almost 50% of arthritic changes [19, 31].

SLAM reconstruction was associated with an increase in postoperative strength by 31% This effect is particularly important because assessing strength by means of a dynamometer represents a highly objective variable that also allows indirect conclusions about pain in the hand. Whereas Abeele and colleagues described significantly reduced grip strength of 58% in comparison to the contralateral hand, the results obtained by Garcia-Elias and colleagues were similar to the percentage of 69 found in our study [17, 18].

Both pain at rest and pain while weight-bearing were significantly reduced in our study. Our results, therefore, largely correspond to the follow-up examinations of SL ligament reconstruction using bone–ligament–bone grafts and the various tenodesis techniques [15–18, 27, 30, 32]. In contrast, 60% of patients complain about persisting pain after dorsal capsulodesis [13, 14, 28, 29].

In summary, this study provides first and promising results of a new method for secondary SL ligament reconstruction. Pain could be significantly reduced and strength was actually increased. The DASH and Mayo questionnaires also yielded positive results. In contrast, the range of motion and SL angle did not change essentially. The high cost of a single SLAM kit and a high invasiveness of the SLAM technique must be viewed critically. An exact placement of the drill guide is imperative to avoid proximal breakout of the tenodesis screw and mediocarpal damage. This needs very high professional expertise in this field. A limitation of the method is the present midcarpal and radiocarpal arthrosis. The sample size of our study was too low for a final evaluation of this method. Although a follow-up of 12 months complies with the period of observation of studies on alternative reconstruction techniques, this short period does not allow any assessment of the long-term effects of this surgical method. Further studies with higher sample sizes and longer follow-up periods are required to be able to confirm the first positive results of this study.

## Compliance with ethical standards

**Conflict of interest** The authors have no financial or personal relationships with other people or organization that could inappropriately influence this work.

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