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Hand Therapy Protocol after Arthroscopic Reconstruction of the Scapholunate Ligament Based on the Pathomechanics and Neuromuscular Control of the Scapholunate Joint

Protocolo de tratamiento en terapia de mano tras la reconstrucción artroscópica del ligamento escafosemilunar basado en la patomecánica y control neuromuscular de la articulación escafosemilunar

Mireia Esplugas[1] Josep Maria Sole Artigau[2]

[1] Institut Kaplan Barcelona, Barcelona, Spain
[2] Tarragona Hand Clinic, Tarragona, Spain

Address for correspondence Mireia Esplugas, MD, Institut Kaplan Barcelona, Barcelona, Spain (e-mail: mireiaesplugas@gmail.com; mireesplugas@gmail.com).

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Abstract

Objective This study aimed to assess the efficacy of a hand therapy protocol following the arthroscopic reconstruction of the dorsal scapholunate ligament according to the Corella technique.

Methods We implemented a protocol lasting less than 3 months, divided into seven therapeutic phases, based on the pathomechanics and neuromuscular control of the scapholunate joint. We provided clear guidelines for the clinical evaluation of the patient.

Results We observed a significant improvement in pain, strength, and mobility in all studied patients 6 months after surgery.

Conclusions The proposed sequential protocol seems an effective strategy for hand rehabilitation following arthroscopic reconstruction of the scapholunate ligament. This protocol has positive implications for the clinical practice and could be a new hand therapy standard.

Keywords
- hand therapy
- scapholunate arthroscopy
- carpal stability
- scapholunate protocol
- scapholunate rehabilitation
- Corella's technique

Resúmen

Objetivo Evaluar la eficacia de un protocolo de tratamiento en terapia de mano tras la reconstrucción artroscópica del ligamento escafosemilunar dorsal, siguiendo la técnica de Corella.

Métodos Implementamos un protocolo de menos de 3 meses de duración escalonado en 7 fases terapéuticas basadas en la patomecánica y el control neuromuscular de la articulación escafosemilunar. Ofrecemos directrices claras para la evaluación clínica del paciente intervenido.

Palabras clave
- artroscopia escafosemilunar
- protocolo escafolunar
- rehabilitación escafosemilunar

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Resultados Observamos una mejora significativa de las medidas de dolor, fuerza y movilidad en todos los pacientes estudiados, a los 6 meses postoperatorios.

Conclusiones El protocolo secuencial propuesto se muestra como una estrategia efectiva para la rehabilitación de la mano tras la reconstrucción artroscópica del ligamento escafosemilunar. Ello tiene implicaciones positivas para la práctica clínica y podría considerarse un nuevo estándar en la terapia de mano.

CARPAL STABILITY AND INSTABILITY DEFINITION

Carpal stability refers to the ability of the wrist to maintain balance and avoid collapse and its symptoms under wrist movement (kinematics), loading (kinetics), or both.[1] The carpus is stable when it can adjust its internal alignment and become a solid block to dissipate the forces passing through it due to movement or load.[2]

The **carpal kinetic and kinematic stability** requires several factors: (1) intact, congruent bone morphology and articular surfaces; (2) competent extrinsic and intrinsic carpal ligaments (static stabilizers); (3) forearm muscles with tendons crossing the wrist and attaching at the bases of the competent metacarpal bones[3,4] (dynamic stabilizers); (4) an effective sensorimotor system[5,6] connecting static and dynamic stabilizers). Dysfunction of any of these four factors can result in symptomatic carpal instability.

Carpal instability does not correspond to a poor carpal bone alignment on complementary examinations (radiography, computed tomography [CT], or magnetic resonance imaging [MRI]). The definition of carpal instability relies on the patient's symptoms during wrist load, movement, or both. The patient with unstable carpus reports one or more of the following symptoms: (1) pain, (2) clicks or popping, (3) loss of strength, and/or (4) loss of maximum joint range. The evolutionary analysis of all these symptoms is a truthful way to assess how the patient's primary instability evolves with the prescribed treatment (preoperative, operative, or postoperative) regardless of the static carpal alignment achieved (visible in a static imaging study).

BIOMECHANICS OF THE CARPUS WITH NO LIGAMENT INJURIES

The muscles responsible for wrist movement attach to the metacarpal bones (except for the flexor carpi ulnaris (FCU), which attaches to the pisiform bone, often considered an accessory carpal bone).

The **distal carpal row** firmly articulates with the base of the metacarpal bones, and its freedom of movement is limited. Likewise, the intrinsic joints of the distal carpal row are highly constrained, and the distal carpal row can resemble a functional block.

The **proximal carpal row** is an "intercalated segment" between the distal carpal row and the distal forearm. The motion and alignment of its three bone components depend on the movements and forces transmitted from the distal carpal row to its surrounding ligaments (midcarpal, radiocarpal, and ulnocarpal ligaments).

Therefore, the distal carpal row provides structural support to the intercalated segment, helping to maintain its alignment and stability. Any change in the position of the distal carpal row may affect the proximal row alignment and stability.

MUSCULAR CONTROL OF THE CARPUS WITH NO LIGAMENT INJURIES

Under axial or muscular load, the distal carpal row undergoes three combined mobility degrees: flexion/extension, radial/ulnar inclination, and external/internal rotation[6–9] (the intracarpal supination/pronation, respectively). Any of these movements transmit proximally to the scaphoid and piriform bones through the periscaphoid and peritriquetral midcarpal ligaments; however, this does not occur with the lunate bone as it does not have midcarpal ligaments attached to it. As a result, the alignment of the lunate bone depends on the competition of the intrinsic SL and lunotriquetral ligaments.

- Loading in the muscles attached to the radial half of the hand (abductor pollicis longus [APL], extensor carpi radialis longus [ECRL], and/or extensor carpi radialis brevis [ECRB]) induces a rotation of the distal row in supination (►**Fig. 1**).
- In contrast, loading on the extensor carpi ulnaris (ECU) muscle, which attaches to the fifth metacarpal bone, induces a rotation of the distal carpal row in pronation (►**Fig. 2**).

Thus, APL, ECRL, and ECRB muscles are the "carpal supinator muscles," while ECU is the "carpal pronator muscle."

BIOMECHANICS OF THE SCAPHOLUNATE JOINT WITH NO LIGAMENT INJURIES

From a kinematic point of view, the SL joint allows coordinated movement between the scaphoid and lunate. During flexion/extension and radial/ulnar inclinations of the wrist, the scaphoid and lunate must move together as a single unit, allowing a smooth, coordinated movement of the first carpal row in flexion or extension.

- In the radial inclination of the wrist, the first carpal row flexes.

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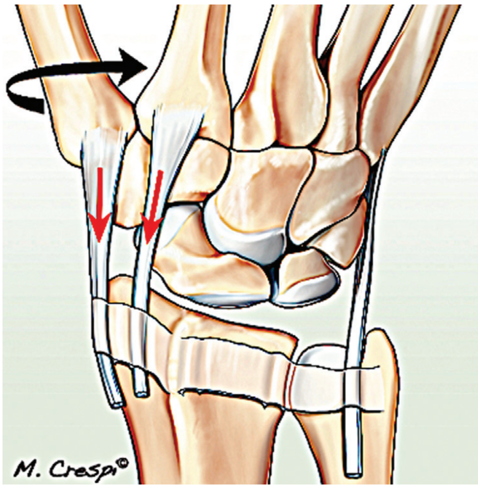

Fig. 1 Isometric contraction of the radial wrist extensor muscles (abductor pollicis longus [APL] and extensor carpi radialis longus [ECRL]) induces an external rotation in supination of the distal carpal row that is transmitted to the proximal row through the midcarpal ligaments.

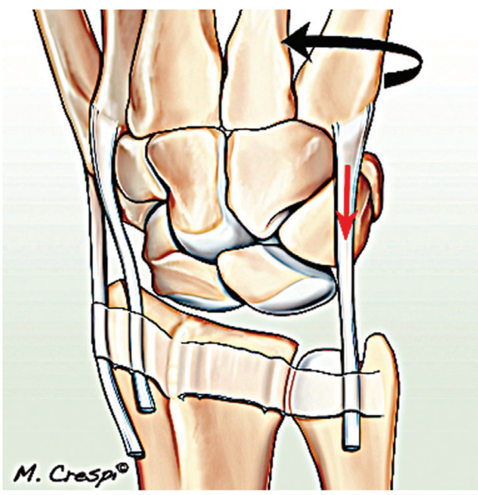

Fig. 2 Isometric contraction of the muscle attaching to the base of the fifth metacarpal (extensor carpi ulnaris [ECU]) induces an internal rotation in pronation of the distal carpal row that is transmitted proximally over the scaphoid and the triquetral through the midcarpal periscaphoid and peritriquetral ligaments.

- In the ulnar inclination of the wrist, the proximal row extends progressively and predictably.
- During wrist flexion/extension, the joint space between the scaphoid and lunate allows a certain degree of independent rotation of different magnitudes of the scaphoid and lunate: this contributes to the ability of the wrist to perform complex movements.
- During wrist flexion/extension, the scaphoid-lunate tandem does not begin its flexion-extension on the radiocarpal joint until the wrist enters its last degrees of mobility.

From a kinetic point of view, the SL joint competence plays a crucial role in transmitting forces through the wrist. During axial loading, such as when grasping an object, the radius transmits forces through the scaphoid and lunate to the remaining of the carpus. The competence of the SL ligament is a key component in this force transmission and helps maintain the stability of the carpal bones under loading.

Indeed, under axial loading, the distal carpal row rotates in pronation, the scaphoid flexes, the piriformis extends, and the entire carpus translates volarly and ulnarly.[7] The flexion moment of the scaphoid is counteracted by the extension moment of the triquetral, and this reverse torsion stabilizes the lunate.

All these carpal alignments adaptive to axial load, mediated by the midcarpal joint anatomy and the competition of the intrinsic and extrinsic carpal ligaments, compact the carpus and prevent it from collapsing under load. As such, it stabilizes and allows the correct transmission of load forces through the carpus.

BIOMECHANICS OF THE SCAPHOLUNATE JOINT WITH INCOMPETENT LIGAMENTS

SL disconnection due to incompetence of its intrinsic ligamentous complex alters carpal kinematics (adaptation of the carpus to wrist movements) and kinetics (adaptation of the carpus to load transmission of loads). In this situation, the scaphoid is disconnected from the remaining bones in the proximal row and behaves like a distal row bone and aligns with it. On the other hand, the lunate closely follows the alignment of the triquetral bone.

Thus, at a **kinematic** level, during flexion/extension or radial/ulnar inclinations of the wrist:

- the scaphoid remaining suspended from the trapezius, trapezoid, and capitate experiences higher mobility over the scaphoid fossa of the radius
- the lunate, still connected to the piriformis, the radius (through the radiolunate ligaments), and the ulna (by the ulnolunate ligament) have reduced mobility.

This fact explains why scapholunate advanced collapse (SLAC) wrists suffer minimal degenerative changes at the articular surface level of the semilunar fossa of the radius. However, they degenerate rapidly at the proximal pole level of the scaphoid and the radial scaphoid fossa.[10]

At a **kinetic** level, carpal loading with an incompetent SL ligament complex gives rise to the following:

- a significant scaphoid flexion (with dorsoradial subluxation of its proximal pole) and an intracarpal rotation in pronation (as distal carpal row drags the scaphoid). These positional changes are known as "scaphoid rotational instability."
- on the other hand, the lunate remaining connected to the piriform experiences an alignment in extension (dorsal intercalated segment instability [DISI]) and a rotation in supination (secondary to the spatial configuration of the triquetral-hamate joint).
- scaphoid pronation and lunate supination lead to a diastasis (a gap) at the SL joint space.

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- this abnormal bone component alignment of the proximal carpal row results in radiocarpal and metacarpal articular surface incongruity, leading to the joint degenerations associated with SLAC.

When the secondary stabilizers of the SL joint (extrinsic ligaments) are competent, these SL malalignments are self-reducing by load relinquishing: the patient presents clinical instability, but static complementary examinations (plain radiology, CT, and MRI) findings can be normal.

When said secondary stabilizers are incompetent, these misalignments become irreducible, static, and rigid, even with no load. In this final phase of SL dissociation, the patient no longer has an unstable carpus under load. In this phase, the carpus is poorly aligned and collapses, resulting in arthropathic signs compatible with the SLAC pattern. However, the carpus can support and transmit loads without giving way or collapsing; as such, it must be considered a stable carpus.[11]

MUSCULAR CONTROL OF THE SCAPHOLUNATE JOINT

We already discussed that the motor muscles of the wrist belong to two groups depending on whether their tendons attach to the radial or ulnar half of the hand because their isometric contraction induces two opposite rotational movements at the distal carpal row level.

- Isometric loading of the APL, ECRL, and ECRB muscles induces supination rotation and extension of the distal carpal row.
- In contrast, the isometric loading of the ECU muscle causes pronation of the distal carpal row.

Supination and extension of the distal row of the carpus can counteract the flexion and pronation alignment of the scaphoid when a carpus with an SL disconnection undergoes an axial load. Therefore, the APL, ECRL, and ECRB muscles are "**SL space stabilizing muscles**." The maximum work capacity of the APL muscle occurs in neutral rotation of the forearm; on the other hand, the ECRL and ECRB muscles are more efficient in forearm pronation.[12,13]

The pronation of the distal row increases the intracarpal pronation of the scaphoid disconnected from the lunate and the carpus is under a load. Therefore, the ECU muscle is the "**SL joint destabilizing muscle**," and its destabilizing effect is independent of forearm rotation.[12,13]

So,

- APL muscle strengthening in neutral forearm rotation can dynamically stabilize the SL joint.[13,14]
- Isometric potentiation of the ECRL and ECRB muscles in forearm pronation may dynamically stabilize the SL space.[13,14]
- Always avoid ECU muscle strengthening in any forearm rotation.[13,14]
- Carpal loading with the forearm in supination should be postponed until restoring the SL joint stability.[13]

This capacity for muscular control over the alignment of the scaphoid and the SL joint space requires joint instability to reduce the dorsoradial translation in intracarpal pronation of the scaphoid, recovering the normal alignment of the radiocarpal and midcarpal joints surfaces by activating the stabilizing muscles of the SL joint (APL, ECRL, and ECRB). When the scaphoid is irreducible due to the incompetence of its primary and secondary ligamentous static stabilizers, the forearm muscles and proprioception[14] (neuromuscular control) have little or no role in stabilizing the joint or preventing progressive collapse of the carpus.[11]

SYMPTOMATOLOGY OF THE PATIENT WITH SCAPHOLUNATE JOINT INSTABILITY

The patient with unstable carpus due to SL disconnection reports one or more of the following symptoms[15]

- central carpal pain (over the dorsal SL joint space) and/or over the dorsoradial area of the articular surface of the radius (corresponding to the impingement area associated with dorsoradial subluxation of the scaphoid).
- popping or protrusions, preferably associated with active flexion-extension of the wrist.
- loss of strength due to axial loading of the wrist (chair-up maneuver) or vertical loading of the wrist (weightlifting) with the forearm pronated and in a horizontal position (forearm parallel to the plane of the floor)
- loss of maximum joint range, especially in extension due to dorsal subluxation of the scaphoid.

We can objectify and measure each of these instability symptoms with one of the following instruments:

- visual analog scale (VAS) to quantify continuous or mechanical pain.
- static radiograph under joint stress (ulnar inclination of the wrist, BUDS[16] [our preferred method], or pencil test) to indirectly evaluate the competence of the static stabilizers of the SL joint.
- a cine-radiology or dynamic ultrasound to demonstrate the popping or ridges during wrist movement.
- a JAMAR-type dynamometer to measure the force transmitted through the carpus in different forearm rotations.
- a goniometer to quantify the range of motion in flexion-extension and the radial-ulnar deviation of the wrist.

Analyzing all these data repeatedly over time is a truthful way to assess the evolution of the patient's clinical instability with the prescribed treatment, regardless of the static carpal alignment achieved (visible in a static imaging study). The evolution over time of the pain, strength, and mobility parameters of the patient's wrist indicates the effectiveness of the preoperative, intraoperative, and/or postoperative treatment prescribed to the patient.

OBJECTIVES OF THE DORSAL SCAPHOLUNATE AND VOLAR LIGAMENT RECONSTRUCTION ACCORDING TO THE CORELLA TECHNIQUE

The arthroscopic reconstruction technique of the SL ligament described in 2011 and 2013[17,18] with distal tendon

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plasty of the flexor carpi radialis (FCR) muscle allows the following:

- to reduce scaphoid flexion and pronation
- to dorsally and volarly stabilize the SL joint space
- to achieve primary stability of the assembly by implanting biotenodesis screws in the scaphoid and lunate
- to increase the resistance to elongation of the plasty by incorporating a high resistance "tape"
- to not use a temporary fixation of the midcarpal or radiocarpal joints with Kirshner wires,
- minimal friction of intra- and extra-articular soft tissues
- to spare the ligaments isodynamic to the SL ligament complex[19]
- to not compromise the cutaneous-ligament-capsular innervation or the competence of the sensorimotor system responsible for the neuromuscular control of the carpus and, more specifically, its first row.[20]

The combination of primary mechanical resistance and the preservation of intra- and extra-articular soft tissues and the nervous system make it our technique of choice, allowing an early integration of the patient into the hand therapy protocol described for their postoperative recovery.

HAND THERAPY PROTOCOL AFTER SCAPHOLUNATE LIGAMENT RECONSTRUCTION WITH THE CORELLA TECHNIQUE (►Table 1)

The surgical technique for SL ligament repair is crucial to treat carpal instability. However, effective post-surgical rehabilitation protocol can significantly improve the outcomes and the time to obtain them. We present below the post-surgical treatment protocol for patients undergoing arthroscopic SL ligament reconstruction according to the Corella technique implemented in our service in 2013.

Although we operated around 50 patients during this decade, we did not start collecting data until less than 2 years ago. Therefore, there are few data collected and analyzed even though our experience with the protocol is long and subjectively positive. We realize our data collection requires prolongation to validate these findings and further optimize our protocol if necessary.

The proposed postoperative rehabilitation protocol relies on all the anatomical, biomechanical, and neuromuscular control concepts of the SL space presented at the beginning of this article. Its main objective is to respect the biological processes of post-surgical repair without compromising ligamentous reconstruction. The protocol has several phases, each focusing on a specific muscular and proprioceptive work. This protocol updates those previously published[21–25] per the latest advances in biomechanical knowledge on the impact of forearm rotation on the stability of the SL joint[13] and the enhancement of this stability in muscle groups.

Protocol fundaments

1- Although the average breaking strength of the dorsal component of the SL ligament is only 250 N, the carpus is subject to much greater loads during activities of daily living. How can the carpus withstand these loads without collapsing and injuring the SL ligament? The answer to this question is the neuromuscular control and its three pillars: muscle, ligament, and sensorimotor system. Correct proprioceptive training of these three elements allows the carpus to withstand loads much higher than it supposedly could. Activating a mixture of mono- and polysynaptic reflexes can achieve this.[20]

This explains why a large part of the post-surgical treatment protocol of the SL ligament aims for the selective enhancement of the SL space stabilizing muscle groups,[12,13] the stimulation of the isodynamic ligaments of the reconstructed SL ligament[16] and the training of the sensorimotor system[20]

2- At the same time, the patient requires education on the physiology, histology, and empirical evidence. We tell patients how we restore the architecture and function of tissues damaged originally or by the surgical act.

Table 1 Patient sample

Identification	Age	Gender	Profession	Number of weeks with symptoms before surgery	Medical specialization service	Injury degree	Number of weeks under therapy	Dominant hand	Affected hand
1	32	Male	Manual worker	5	Hand	IV	20	Right	Right
2	38	Female	Elite athlete	8	Hand	III	18	Right	Right
3	34	Male	Policeman	6	Hand	III	14	Right	Right
4	52	Male	Manual worker	4	Hand	III	20	Right	Right
5	34	Male	Policeman	2	Hand	IV	16	Right	Right
6	36	Male	Manual worker	8	Hand	III	24	Left	Right
7	48	Male	Hairdresser	11	Hand	III	18	Right	Right
8	18	Male	Football player	10	Hand	III	12	Right	Right
9	42	Male	Engineer	8	Hand	IV	15	Right	Right

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Therefore, the hand therapist should know the regulation of these tissues, the factors involved in their repair, the criteria for applying each technique, and the surgical procedure used by the hand surgeon who operated on the patient.

Treatment phase 1: First 2 weeks

This phase begins 48 hours after surgery and continues until the 14th day after surgery (**duration: 2 weeks minus the first 2 days**).

Objective

Avoid pro-inflammatory stimuli that, due to fibrinopeptide action and increased capillary permeability, result in exudation to adjacent tissues, which can create fibrin networks with potential mobility restriction.

Methodology

- We provide the patient with a strict limb positioning guideline, favoring its anti-inflammatory effect by keeping the limb in a lower position and stimulating lymphatic drainage and the axillary nodes.
- To allow adequate biological rest of the affected and surrounding tissues, it is recommended to make a resting splint with slight intracarpal supination, ulnar deviation, and wrist extension for 24/7 use during the first 2 weeks and nighttime use alone until week 5.
- After suture removal, the patient must begin treatment with contrasting baths, three times a day, as follows:
  - 7' with the limb submerged in hot water between 35° - 40°,
  - 1' with the limb submerged in cold water between 10° - 15°.
  - This is followed by two more cycles of 4' in hot water and 1' in cold water consecutively.
  - Splint replacement after the contrasting baths.

2) This phase also trains the patient on selective **muscle activation and recognition** of the dynamic stabilizers of the SL space, i.e., the ECRL, ECRB, and APL muscles.

   - We recommend performing this muscle activation training three times a day without removing the splint.

3) During the second week, we begin the **gradual image training** program following its operating structure based on:

   - interhemispheric discrimination
   - motor/kinesthetic/visual imagination
   - mirror therapy.

Treatment phase 2: Third week

This phase ranges from day 15 to 21 after surgery (**duration: 1 week**).

Objective

Begin **isometric potentiation** of the SL stabilizing muscles, i.e., ECRL, ECRB, and APL.[12,13]

Fig. 3 Isometric potentiation of extensor carpi radialis longus [ECRL] and extensor carpi radialis brevis [ECRB] on the hand table.

Methodology

1) Continue the contrasting baths.
2) Add self-massage to the scars to enhance their desensitization and avoid adhesions (especially those from FCR plasty and located at the level of the scaphoid distal pole). 3) Remove the splint only to perform muscle-strengthening exercises.
   - Ideally, work the APL (contrary extension of the first metacarpal) in neutral forearm rotation
   - At the same time, strengthen the radial extensors of the wrist (contrary extension of the second and third metacarpal bones) with the forearm in pronation.
   - To simultaneously enhance APL, ECRL, and EPB, do it with the forearm in pronation.
   - Avoid forearm supination, especially during muscle-strengthening exercises.
   - Program isometric work in three series of eight repetitions for 10 seconds (3 S x 8 REP x 10") three times a day: 10 am, 4 pm, and 10 pm (►**Fig. 3)**.

Treatment phase 3: Fourth week

This phase begins on day 22 after surgery and **lasts for one week**.

Objective

Initiate active and passive movement of the **midcarpal joint**.

The main objective in this phase is to promote functional flexion-extension of the wrist without risking the reconstruction plasty. To do this, teach the patient to flex and extend the wrist through the midcarpal joint. This movement is the most used for activities of daily living (►**Fig. 4**).

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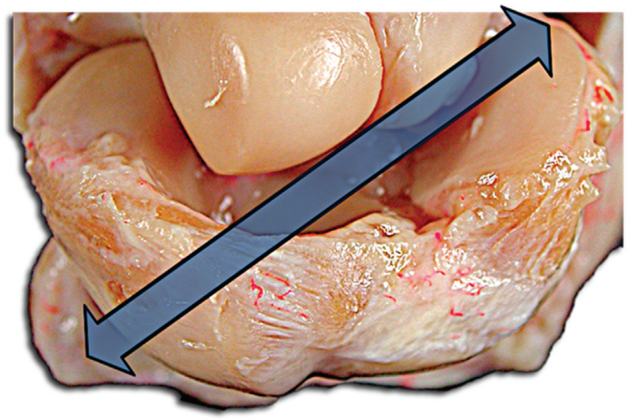

Fig. 4 Anatomical view of the midcarpal joint and axis of the plane following the movement generating it. This movement is called dart-throwing motion (DTM) and follows the dart-throwing plane (DTP). In this movement, the wrist extends in a radial inclination and flexes in an ulnar inclination.

Recovering maximum mobility at the midcarpal joint is much more beneficial for the patient than restoring mobility at the radiocarpal joint.

The midcarpal joint may associate the flexion/extension movement of the wrist with its inclinations. Thus, extension is associated with radial inclination, while flexion is associated with ulnar inclination.[26]

When the SL joint is in normal alignment and the maximum range of motion, i.e., the dart-throwing motion, is not reached, the wrist mobility generated in the midcarpal joint does not lead to a rotation movement of the proximal carpal row. In these conditions, the mobility of the midcarpal joint does not induce rotational movements at the level of the SL joint; therefore, it does not risk the repaired ligamentous complex.[27]

Methodology

1) Continue the same pattern of contrasting baths and scar massage therapy.
2) Protect the wrist with the splint at night and during uncontrollable risk activities (wandering on the street, playing with children or pets, going to a place full of people, etc.).
3) In environmental control situations, the wristband is not necessary.
4) Teach the patient to perform the dart-throwing motion. This movement is not easy for the patient to understand. The wrist must go from extension in radial deviation to flexion in ulnar deviation. This movement requires ECRL, ECRB, and flexor carpi ulnaris (FCU) muscle activation.
5) Carefully analyze how the patient performs the movement because they usually do pure wrist inclinations which are highly contraindicated (remember from the biomechanics of the SL joint with no ligamentous injuries section that pure wrist inclinations are associated with flexion-extension of the first carpal row that can put the SL joint under rotational stress).
6) Once the patient learns how to perform the dart-throwing motion, program the midcarpal work in both wrists simultaneously for 5 minutes every 3 hours while the subject is awake.

Treatment phase 4: Fifth week

This phase begins on the day 28 after surgery and **lasts for one week**.

Objective

Initiate active and passive movement of the **radiocarpal joint**.

Methodology

1) Continue with the same pattern of contrasting baths and scar desensitization.
2) Protect the wrist with the splint only at night and during uncontrollable risk activities.
3) Initially, promote global flexion-extension rotation of the proximal carpal row at the level of the radiocarpal joint, promoting lateral wrist inclinations. In fact, in the ulnar inclination of the wrist, the proximal row extends, and the radial inclination of the wrist flexes the proximal row.
4) Once radiocarpal mobility has been achieved through lateral deviations of the wrist, it is easier to request active/passive angular movement of the radiocarpal joint through pure flexion-extension of the wrist.
5) In the initial sessions, work through static positions defined per the total end range time (TERT) concept,[28] to increase the elasticity of rigid tissues based on long exposures of low load stretching following the low load prolonged stretch (LLPS) concept.[29] Thus, work with tension positioning between 30' and 2 hours once a day, accompanied by splinting if necessary to prolong the tensile effect on the tissues. This tension has a low load, and the patient must perceive it as a bearable tightness with no pain.

Treatment phase 5: Sixth week

This phase begins on day 35 after surgery and **lasts for one week**.

Objective

Initiate **proprioceptive neuromuscular facilitation**.[30]

Methodology

1) Remove the wristband permanently.
2) Recommend contrasting baths only in case of residual or localized edema.
3) Start the proprioceptive work at a sensory level and progress until the motor control work. Both have been facilitated by the previous gradual training of motor images (in the second postoperative week).
4) **Sensory proprioception** consists of training the patient to discern the position and movement of their own body and wrist without the need for visual information ("joint

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position sense") added to the work of gradual motor imagination in its intermediate phase of generating visual and kinesthetic images.

5) 5) The **motor control** techniques according to Kabat rely on repeated contraction, rhythmic stabilization (a technique to improve dynamic joint stability), holding and releasing, movement repetition, and stretching.[30]
6) Treatment progresses by adding weight during midcarpal movement. According to Salles et al.,[31] joint position sense (JPS) may improve with strength exercises. Therefore, weight addition to the wrist movement during the dart-throwing motion promotes eccentric ECRL and ECRB contraction.
7) Finally, ask the patient to keep the wrist as still as possible while disruptions occur in different senses. Add changes in position, the amount of force, or the speed of execution32 according to Hagert.[20] This author reports that the eccentric ECRL contraction influences the coactivation pattern (co-contraction) of the FCU, promoting carpal stability.

Treatment phase 6: Seventh week

This phase begins on day 42 after surgery and **lasts for two weeks**.

Objective

Start **full forearm pronosupination and gyroscope exercises**.[33]

Methodology

1) Continue working on the complete range of motion (ROM) using techniques avoiding the so-called painful hard-end feel, adding pronosupination of the forearm.
2) Introduce a gyroscope exercise (Powerball ® 280Hz Gyroscope Wrist Trainer Pro) to promote reactive muscle activation (RMA) by forcing the forearm muscles to react in unpredictable ways. The gyroscope rotation must be clockwise for the right wrist and counterclockwise for the left wrist. As such, request activity from the ECRL and the FCU in each wrist, thus reactively activating the muscles responsible for the dart-throwing motion.

Treatment phase 7: Nineth week

This phase begins on day 56 after surgery and has an **indefinite duration (final phase)**.

Objective

Achieve **full ROM** and **initiate axial carpal loads** to reeducate carpal kinetics.

Methodology

1) Progress from a soft axial load on a soft ball, with the full fist, first with the wrist in extension and then with the wrist in extension under load.
2) In this phase, the tension on passive carpal stabilizers under axial load (the carpal antipronator ligaments[19]). This explains why the short repetition sets require specific guidelines for causing no pain, i.e., three sets of 10 repetitions of 15"-20."

STUDY OF MEDIUM-TERM CLINICAL OUTCOMES OF THE LAST NINE PATIENTS SUBJECTED TO THE PROTOCOL

Methodology

We prospectively examined nine patients diagnosed with grade III-IV SL dysfunction according to the EWAS classification, operated on by the same hand surgeon (ME) using arthroscopic reconstruction of the dorsal SL ligament with augmented FCR-plasty per the Corella technique.

The patients had been admitted to the Hand therapy service before surgery, and their follow-up period went on the sixth postoperative month. All underwent the hand therapy protocol presented above under the supervision of the same hand therapist (JMS).

Patient selection occurred per the criteria detailed below.

Inclusion Criteria

Consecutive patients referred to the hand therapy unit since 2021 after performing arthroscopic ligamentoplasty of the SL ligament according to the Corella technique (►**Table 1**).

Exclusion Criteria

Patients under 18 or over 60 years old, undergoing treatment at another center, with a history of surgery on the affected carpus, not operated on by the first author (ME), or not submitted to the Corella technique.

Clinical Outcome Assessment

As mentioned in the previous section, although the first author (ME) has been performing the Corella technique since 2013 and the co-author (JMS) began implementing this protocol in 2014, we do not consider it complete and updated per the latest biomechanical studies[13] until 2020. This explains why we started collecting prospective data only in 2021. As such, our series is short but homogeneous: the nine patients resided in the province of Tarragona, and they were operated on by the same surgeon and evaluated pre- and postoperatively by the same hand therapist.

The assessment of clinical outcomes used the following instruments:

1) The study of perceived pain using a numerical visual analog scale (VAS).
2) Strength evaluation using three measures of maximum grip strength, maximum non-painful grip, and maximum grip of the unaffected hand with an electronic dynamometer (►**Fig. 5**) with the forearm in neutral rotation and the elbow at 90° of flexion. Each strength measurement occurred three times and is expressed as the mean value obtained.
3) Functionality evaluation used the validated Quick Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire in Spanish.[34]

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Fig. 5 Digital dynamometer for measuring wrist strength.

Data collection occurred before surgery and 6 months after the procedure. Preoperative measurements happened a week before surgical repair, while follow-up measurements occurred 26 weeks after surgery.

Outcome Analysis (►Tables 1, 2, 3, and 4)

1) The patients included in the study were, on average, 37.1 years old (standard deviation [SD], 9.85; range, 18–52). The sample had 88.88% men and 11.22% women (►**Table 1**).
2) Surgery occurred on the dominant hand in 88.88% of the patients and 11.22% on the non-dominant hand (►**Table 1**).
3) All patients presented an improvement in perceived pain, with an average decrease of 79.27% (►**Table 2**).
4) All patients improved their maximum grip strength after surgery: the pre-surgical average value was 21.4 kg, while the postoperative average value at 6 months was 37.5 kg, representing a 43% increase (►**Table 3**).
5) All patients also improved their non-painful grip strength after surgery: we started from a preoperative average of

Table 2 Collection of data on pain perceived by the patient per the visual analog scale (VAS). At 6 months postoperatively, all patients presented pain improvement (average improvement, 79.27%)

	PAIN (VAS/10)		
Identification	Preoperative	Postoperative	Difference
1	9	5	4
2	7	1	6
3	8	0	8
4	3	0	3
5	7	0	7
6	9	3	6
7	6	3	3
8	6	2	4
9	5	0	5

Table 3 Data collection of the total grip strength of the operated wrist (*gray*), the pain-free grip strength of the operated wrist (*yellow*), and the grip strength of the contralateral wrist (unoperated wrist) (*blue*). All strength measurements improved at 6 months, although patients 1, 5, 6, 7, and 8 continued to report pain at the end of the test (patient 1: in the last 13 kg; patients 5, 6, and 7: in the last 2 kg; patient 8: in the last 4 kg)

	Maximum grip strength			Pain-free maximum grip strength			Grip strength in the unoperated hand		
Identification	Preoperative	Postoperative	Difference	Preoperative	Postoperative	Difference	Preoperative	Postoperative	Difference
1	18	25	7	9	12	3	34	38	4
2	40	56	116	26	56	30	52	53	1
3	29	52	23	22	52	30	42	45	3
4	10	19	9	10	19	9	40	40	0
5	20	52	32	17	50	33	45	48	3
6	15	32	17	10	30	20	32	38	6
7	8	18	10	3	16	13	35	40	5
8	32	41	9	30	37	7	40	41	1
9	21	43	22	15	43	28	39	38	−1

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Table 4 The score of the Quick Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire validated for the Spanish population improved significantly in all patients (mean functional improvement, 86.16%)

	QUICK DASH (%)		
Identification	Preoperative	Postoperative	Difference
1	84.09	54.54	−35.14
2	38.63	0	−100
3	47.72	0	−100
4	81.81	11.36	−86.11
5	68.18	0	−100
6	77.27	9.09	−88.24
7	72.72	6.81	−90.64
8	34.09	2.27	−93.34
9	47.72	0	−100

Table 5 Protocol summary

Week	Suggested exercises	Exercise plan	Rationale	Progression criteria
0-2/52	Anti-edema measures: contrasting baths, recumbency. Start motor control: teach extensor carpi radialis longus (ECRL) and abductor pollicis longus (APL) activation and start graduated motor image training	In pronation, activate ERCL in isolation. In the neutral position, activate the APL. Gradual image training of motor skills in three steps: left/right discrimination, motor images, and mirror therapy	Movement is not allowed. This phase aims to reduce/avoid swelling and pain and begin motor control of the midcarpal supinator muscles and brain plasticity training	Able to sense ERCL and APL activation. Able to understand the muscle anatomy and biomechanics. Understand the importance of avoiding swelling. Sequential administration of GMI. The patient and the therapist must have a flexible approach to move back and forth in the individual treatment process
2/52-3/52	ECRL and APL isometric strength. Strengthening with no pain or movement progression. Five sets of 10 repetitions are recommended, three times a day	In pronation, ECRL isometric exercises. In neutral position, APL isometric exercises. No amplitude of movement, no wrist deviations, and relaxed fingers in the resting position	Activate/strengthen midcarpal supinators with no range of motion (ROM). To take advantage of the biomechanics, that the ECRL is in pronation and the APL is in neutral position	Must maintain muscle control of the supinators without generating ROM
3/52-4/52	Start of dart throwing motion (DTM) training. Movement without pain or reaching the limits of movement	With elbows on the table, perform DTM from extension in radial deviation to flexion in ulnar deviation with the hands in anatomical position	The use of the midcarpal joint is allowed as long as the limits are not reached. The use of the midcarpal joint does not tension the first carpal row and does not generate radiocarpal movement	No pain in any position. Able to perform DTM in controlled position
4/52-5/52	Active/passive radiocarpal movement. Early movement involving the proximal carpal row	Controlled radiocarpal joint movement from passive to active. Flexion/extension and ulnar deviation/radial deviation. Work on the elastic limits of the tissue.	Intrinsic rotation of the first carpal row is allowed. Concomitant progress of scar desensitization plus radial deviation in extension and flexion. Pain is not admitted but the	Able to perform ROM in flexion/extension with no pain

(*Continued*)

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Table 5 (*Continued*)

Week	Suggested exercises	Exercise plan	Rationale	Progression criteria
			sensation of tension is reasonable following the total end range time (TERT) concept	
5/52-6/52	Start controlled active proprioceptive exercises. Reactive muscle activation (RMA)	With both hands on an unstable surface in a pronated/neutral position. Progress without visual control and on different surfaces.	Early exposure to controlled joint instability. Neuromuscular control training: monosynaptic reflex and supraspinal control	Low load without pain. Able to control wrist position with no tremors or dystonia
6/52-8/52	Complete pronation-supination movement. Beginning of multidirectional resisted exercises: gyroscope	Complete supination of the forearm and wrist is allowed. Five minutes, twice a day, of gyroscope training to gain strength and motor control	Greater complexity and resistance to proprioception. Work on ROM in full pronation/supination	Exercise with no pain. Advances to normalize pronosupination. Able to perform gyroscope training until muscle fatigue.
8/52-6 months	Complete wrist ROM and improved wrist proprioception. Progressively expose the carpus to axial loads.	Begin to generate axial loads against a punching bag. Progress to full flexion of the upper limb with the wrist, and, finally, progress to regular flexion of the upper limb in wrist extension. Specific conditioning for sport/work	Increased controlled stress of the scapholunate ligament. Work until ligament fatigue with no pain	Higher load with no pain. Must be able to perform upper limb flexions, progressing from full to regular fist. Sets of 10 repetitions are recommended. Resume sport/work activities

15.7 kg and registered an average of 35 kg 6 months after surgery, representing a 72% increase (►**Table 3**).

6) The maximum grip strength of the non-operated hand also improved: the initial average value was 39.8 kg, and, at the end of the treatment protocol, the average value was 42.2 kg (6% increase). This occurs because both upper extremities are under axial loading in the final phase of treatment (►**Table 3**).
7) Finally, the analysis of the outcomes from the functional assessment of the upper limb using the Quick DASH shows a significant decrease, with an average improvement of 86.16% at 6 months (►**Table 4**).

Discussion

The treatment team for the nine patients included (1) an expert surgeon who has already largely overcome the learning curve of a repair technique that maximally protects the integrity of the carpal structures and (2) a highly experienced hand therapist who rationally implemented the postoperative protocol presented by us and based on basic sciences (physiology, biology, anatomy, and biomechanics) of the carpus and wrist. Even so:

- Although all patients improved their pain level by an average of 5/10 points, only 4/9 patients reported no pain in their activities of daily living.
- Although all of them increased the transmission of loads through their wrist and their grip strength increased by an average of 14.88 kg, 5/9 of the patients still reported pain at their maximum load.
- Although all patients improved their hand function (the Quick DASH score improved, on average, 52 points), only 4/9 patients presented complete normalization.

Therefore, one might think that, even under presumably optimal therapeutic conditions, SL ligament reconstruction surgery better restores the mechanical-functional demands than the painful symptoms in the medium term. This must be a significant aspect to explain to the patient preoperatively to adapt their postoperative expectations to reality: pain can persist in activities of daily living and when the wrist is under load, even though it should be less intense (<5/10).

This hand therapy protocol after dorsal and volar SL ligament reconstruction is indicated only when ligamentoplasty is not associated with temporary stabilization of the midcarpal or radiocarpal joint with Kirshner wires or when reconstruction ensures the primary perioperative stability of the system (correct fixation of the ligamentoplasty with biotenodesis screws supported or not with a biological plasty augmentation system with a tape). If intraoperative stability is uncertain, the periods from the different phases can be lengthened or postponed. However, we believe it is critical to

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respect the staggered temporal sequence to favor the recovery of maximum functional mobility, the highest static stability (integration and normal tension of the plasty), and the most synchronized dynamic stability (neuromuscular control of the carpus and its proximal row) with no pro-inflammatory tissue aggression during the process. ►**Table 5** shows a summary of the protocol.

Conclusion

Considering the small size of our sample, the study lacks statistical power. However, the data support the effectiveness of the implemented postoperative protocol and show fundamental clinical-functional benefits for the patient undergoing arthroscopic repair of the SL ligament using the Corella technique. This is why we wanted to share our protocol and its sequential and progressive phases with the scientific community even though we continue to collect data. We believe it is an efficient, effective, updated, and complete tool for the therapeutic benefit of our patients.

Conflict of Interest
None.

References

1 The Anatomy and Biomechanics Committee of the International Federation of Societies for Surgery of the Hand. Definition of carpal instability. J Hand Surg Am 1999;24(04):866–867
2 Garcia-Elias M. Kinetic analysis of carpal stability during grip. Hand Clin 1997;13(01):151–158
3 Salva-Coll G, Garcia-Elias M, León-López MT, Llusa-Perez M, Rodríguez-Baeza A. Effects of forearm muscles on carpal stability. J Hand Surg Eur Vol 2011;36(07):553–559
4 Salvà Coll G, Garcia-Elias M, Lluch Bergadà Á, León López MM, Llusá Pérez M, Rodríguez Baeza A. [Carpal dynamic stability mechanisms. Experimental study]. Rev Esp Cir Ortop Traumatol 2013;57(02):129–134
5 Hagert E. Wrist ligaments, innervation patterns and ligamento-muscular refexes. Thesis for doctoral degree (Ph.D.) Karolinskainstitutet; 2008
6 Salva-Coll G, Garcia-Elias M, Hagert E. Scapholunate instability: proprioception and neuromuscular control. J Wrist Surg 2013;2(02):136–140
7 Kobayashi M, Garcia-Elias M, Nagy L, et al. Axial loading induces rotation of the proximal carpal row bones around unique screw-displacement axes. J Biomech 1997;30(11-12):1165–1167
8 Salva-Coll G, Garcia-Elias M, León-López MM, Llusa-Perez M, Rodríguez-Baeza A. Role of the extensor carpi ulnaris and its sheath on dynamic carpal stability. J Hand Surg Eur Vol 2012;37(06):544–548
9 León-López MM, García-Elías M, Salvà-Coll G, Llusá-Perez M, Lluch-Bergadà A [Muscular control of scapholunate instability. An experimental study]. Rev Esp Cir Ortop Traumatol 2014;58(01):11–18
10 Watson HK, Ballet FL. The SLAC wrist: scapholunate advanced collapse pattern of degenerative arthritis. J Hand Surg Am 1984;9(03):358–365
11 Salvà-Coll G, Garcia-Elias M, Lluch-Bergada A, Esplugas M, Llusa-Perez M. Kinetic dysfunction of the wrist with chronic scapholunate dissociation. A cadaver study. Clin Biomech (Bristol, Avon) 2020;77:105046
12 Salva-Coll G, Lluch A, Esplugas M, et al. Scapholunate and lunotriquetral joint dynamic stabilizers and their role in wrist neuromuscular control and proprioception. J Hand Ther 2023;S0894-1130(23)00138-2. en prensa Doi: 10.1016/j.jht.2023.09.011
13 Esplugas M, Lluch A, Salva-Coll G, et al. Influence of forearm rotation on the kinetic stabilizing efficiency of the muscles that control the scapholunate joint. Clinical application in proprioceptive and neuromuscular rehabilitation programs. J Hand Ther 2023;S0894-1130(23)00137-0. en prensa Doi: 10.1016/j.jht.2023.09.012
14 Hagert E, Lluch A, Rein S. The role of proprioception and neuromuscular stability in carpal instabilities. J Hand Surg Eur Vol 2016;41(01):94–101
15 Kuo CE, Wolfe SW. Scapholunate instability: current concepts in diagnosis and management. J Hand Surg Am 2008;33(06):998–1013
16 Puig de la Bellacasa I, Salva-Coll G, Esplugas M, Quintas S, Lluch A, Garcia-Elias M. Bilateral Ulnar Deviation Supination Stress Test to Assess Dynamic Scapholunate Instability. J Hand Surg Am 2022;47(07):639–644
17 Corella F, Del Cerro M, Larrainzar-Garijo R, Vázquez T. Arthroscopic ligamentoplasty (bone-tendon-tenodesis). A new surgical technique for scapholunate instability: preliminary cadaver study. J Hand Surg Eur Vol 2011;36(08):682–689
18 Corella F, Del Cerro M, Ocampos M, Larrainzar-Garijo R. Arthroscopic ligamentoplasty of the dorsal and volar portions of the scapholunate ligament. J Hand Surg Am 2013;38(12):2466–2477
19 Garcia-Elias M, Puig de la Bellacasa I, Schouten C. Carpal ligaments. A functional classification. Hand Clin 2017;33(03):511–520
20 Hagert E. Proprioception of the wrist joint: a review of current concepts and possible implications on the rehabilitation of the wrist. J Hand Ther 2010;23(01):2–17
21 Guisasola E, Carratalá Baixauli V, Calduch Selma F, Lucas García F. El papel de la rehabilitación tras las reparaciones de las inestabilidades de muñeca. Rev. Iberoam. Cir. Mano. 2016;44:131–142
22 Guisasola E, Calduch F. Tratamiento rehabilitador tras cirugía artroscópica de la inestabilidad de la muñeca. Rev. Esp. Artrosc. Cir. Articul. 2014;21:14–27
23 Holmes MK, Taylor S, Miller C, Brewster MBS. Early outcomes of 'The Birmingham Wrist Instability Programme': A pragmatic intervention for stage one scapholunate instability. Hand Ther 2017;22(03):90–100
24 Esplugas M, Garcia-Elias M, Lluch A, Llusá Pérez M. "Role of muscles in the stabilization of ligaments - deficient wrists". J Hand Ther 2016;29(02):166–174
25 Wolff AL, Wolfe SW. Rehabilitation for scapholunate injury: Application of scientific and clinical evidence to practice. J Hand Ther 2016;29(02):146–153
26 Feehan L, Fraser T. Early controlled mobilization using dart-throwing motion with a twist for the conservative management of an intra-articular distal radius fracture and scapholunate ligament injury: A case report. J Hand Ther 2016;29(02):191–198 [Internet]
27 Garcia-Elias M, Alomar Serrallach X, Monill Serra J. Dart-throwing motion in patients with scapholunate instability: a dynamic four-dimensional computed tomography study. J Hand Surg Eur Vol 2014;39(04):346–352
28 Flowers KR, LaStayo P. Effect of total end range time on improving passive range of motion. J Hand Ther 1994;7(03):150–157
29 Light KE, Nuzik S, Personius W, Barstrom A. Low-load prolonged stretch vs. high-load brief stretch in treating knee contractures. Phys Ther 1984;64(03):330–333

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30 Voss DE. Proprioceptive neuromuscular facilitation. Am J Phys Med 1967;46(01):838–899
31 Salles JI, Velasques B, Cossich V, et al. Strength training and shoulder proprioception. J Athl Train 2015;50(03):277–280
32 Zeliha B, Ferdi B. Nihal, Mustafa Ö. The effectiveness of scapular stabilization exercise in patients with subacromial impingement syndrome. J Back Musculoskeletal Rehabil 2011;24:173–179
33 Balan SA, Garcia-Elias M. Utility of the Powerball in the invigoration of the musculature of the forearm. Hand Surg 2008;13(02):79–83
34 García LA, Francisco S, Rodríguez MC. Validation of the Spanish version of the short Disabilities of the Arm, Shoulder, and Hand Scale - Quick DASH. Rev Colomb Ortop Traumatol 2018;32(04):215–219

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