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The effect of rotator cuff tear on scapular motion and shoulder function

PhD thesis

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List of abbreviations

AC	- acromioclavicular joint
AS	- after surgery subgroup
ASES	- American Shoulder and Elbow Surgeons score
BMI	- body mass index
BSI	- before surgery injection subgroup
BSN	- before surgery native subgroup
CM	- Constant- Murley score
dgr	- degree
GH	- glenohumeral
GT	- greater tuberosity
HG	- healthy group
HH	- humeral head
ISB	- International Society of Biomechanics
ISP	- infraspinatus muscle
ISP-I	- insertion area of the infraspinatus
LHBT	- long head biceps tendon
LT	- lesser tuberosity
MRI	- magnetic resonance imaging
n.s.	- not significant
RC	- rotator cuff
ROM	- range of motion

SC	- sternoclavicular join
SD	- scapular dyskinesis
SD	- standard deviation
SG	- surgery group
SHR	- scapulohumeral rythm
SSC	- subscapularis muscle
SSP	- supraspinatus muscle
SSP	- insertion area of the supraspinatus
ST	- scapulothoracal
STAM	- scapulothoracic abnormal motion
TM	- teres minor muscle
OA	- osteoarthritis
ULEMA	- Upper Limb Evaluation in Motion Analysis
VAS	- visual analog scale

1. Introduction

The shoulder is the joint with the highest range of motion (ROM) in the human body. Shoulder pain, the third most common musculoskeletal pain is one of the leading complaints of musculoskeletal disorders, affecting 15-20% of the population according to the literature. [1, 2, 3] One of the most common abnormalities detected in the shoulder joint is the lesion of the rotator cuff (RC). Rupture of the RC can lead to deterioration of shoulder function at any age. Injuries predominate at a young age, degenerative abnormalities prevailingly occur at an older age. [4] This may result in a reduced ROM of the shoulder and abnormal shoulder muscle function. [5-8]

Movements of the shoulder girdle are based on the movements of the scapula. Abnormalities in scapular movements are called scapular dyskinesis (SD). Scapular dyskinesis may be presented in healthy individuals [9], however, its prevalence is much higher in shoulder disorders, reaching up to 87%. [10]

Simultaneously with RC tears, the presence of SD can be detected in many instances. [11] Lifting our arm is possible through the coordinated action of scapulothoracic and glenohumeral movements. In RC rupture, an abnormal movement pattern is created, the whole kinetic chain is disturbed. [12-15]

It is however still not clear whether the persistence of scapular dyskinesis leads to RC tear and pain or the rupture of the RC and pain trigger SD? In other words, which comes first, RC rupture and pain or SD?

A more accurate understanding of scapular movements in RC tears could be a help of great importance in the interpretation of SD. It would improve the success rate of conservative therapies, significantly reducing the high cost of shoulder surgery. [16] It could also improve the effectiveness of postoperative physiotherapy treatments and would optimise the focus of treatments on the muscle groups and scapular directions involved.

1.1. Rotator cuff (RC)

1.1.1. Anatomy of the footprint of the RC

When identifying the rotator cuff tendon, it is difficult to separate the supraspinatus (SSP) and infraspinatus (ISP) muscles. [17] Consequently, previous anatomy studies have been inaccurate regarding footprint distribution. The footprint of the SSP was depicted as inserting to the upper surface of the tuberculum maius, while the ISP tended to insert to the posterior surface of the tuberculum maius. [18-21]

We know from recent studies that the SSP insert to a much smaller area of the footprint than it was previously imagined. [22, 23] This finding should be taken into account in future RC reconstruction. [24] In Figure 1. we show the anatomy of the former and the current SSP and ISP footprint, and in Table 1. the SSP and ISP footprint dimensions.

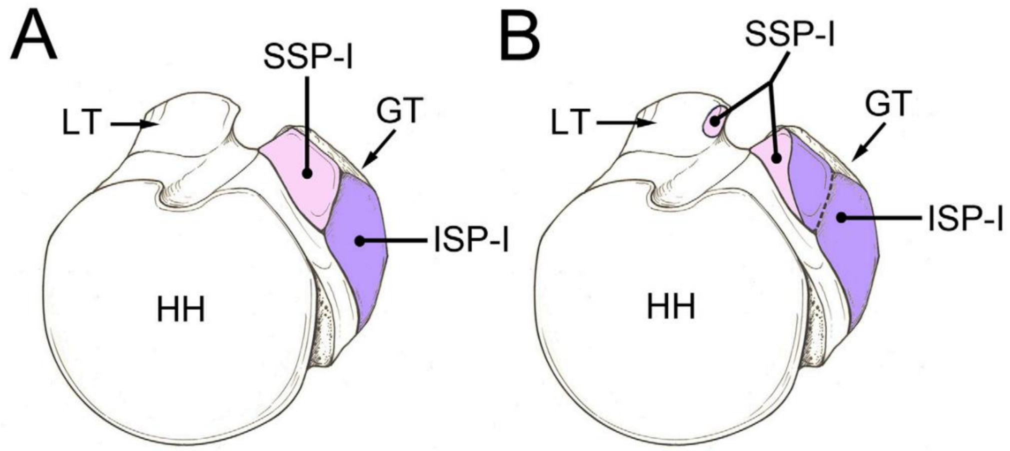

Figure 1. Illustrations of the superior view of the right humerus, depicted the humeral insertions of the SSP and ISP. [22]

A: The picture based on the earlier accepted philosophy of the anatomy of the humeral insertions. The SSP is depicted to insert into the highest portion and the ISP into the middle part of the GT.

B: The picture based on the findings of the latest study. The ISP insertion area covers approximately half of the highest point of the GT and the entire area of the middle portion. The SSP insertion area is shown at the anteromedial part of the highest part and is sometimes located at the top of the LT.[22]

Table 1. Measurements of the footprints of the SSP and ISP. [22]

SSP	Average and Standard Deviation (mm)
Maximal medial-to-lateral length	6.9 ± 1.4
Anteroposterior width of medial margin	12.6 ± 2.0
Anteroposterior width of lateral margin	1.3 ± 1.4
ISP	
Maximal medial-to-lateral length	10.2 ± 1.6
Anteroposterior width of medial margin	20.2 ± 6.2
Anteroposterior width of lateral margin	32.7 ± 3.4

In studies on subscapularis (SSC) insertion, early anatomical investigations suggested that the SSC insertion was rather trapezoidal. [25, 26] More recent studies suggest a more comma-like shape. [27] The upper half is tendinosus, while the lower half has a muscular structure. The upper 1/4 has a prominent role in stabilizing the biceps tendon. [28] The insertion and structure of the SSC and footprint dimensions are shown in Figure 2. and Table 2.

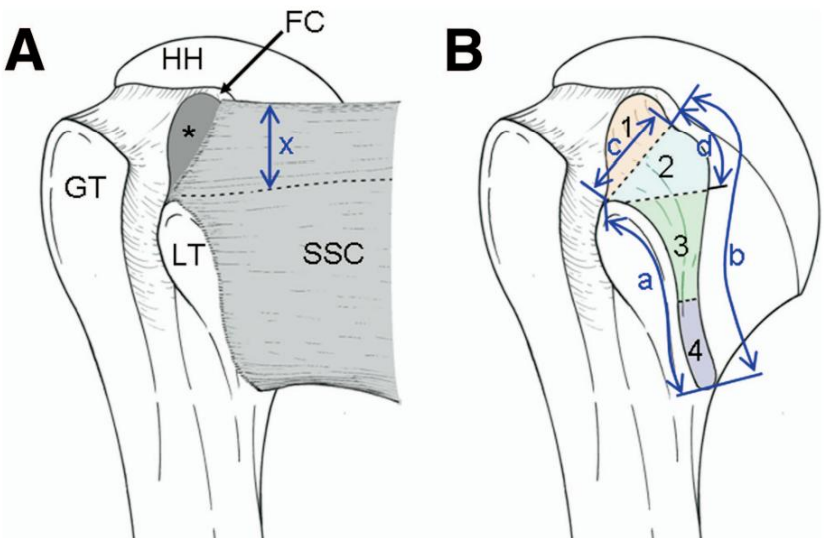

Figure 2. Diagrams of (A) right SSC insertion and (B) right shoulder SSC footprint. The longitudinal diameter of the superior part of intramuscular tendons is indicated by (x). Each area in the SSC footprint is depicted by a number: 1. tendinous slip (*), 2. insertion of the upper part of intramuscular tendon, 3. further tendinous insertion, 4. muscular insertion. Margins of the subscapularis footprint: a. lateral margin, b. medial margin, c. superior-most lateral margin, d. superior-most medial margin. [28]

Table 2. Dimensions of SSC footprint and superior-most insertion of SSC tendon. [28]

SSC	Average and Standard Deviation (mm)
Whole footprint of subscapularis muscle	
Lateral margin (a)	37.6± 6.6
Medial margin (b)	40.7± 6.9
Superior-most insertion of subscapularis tendon	
Superior-most lateral margin (c)	12.5± 1.9
Superior-most medial margin (d)	6.5± 1.4
Cranial part of intramuscular tendons	
Longitudinal diameter (x)	9.5± 1.3

1.1.2. Function and biomechanics of the rotator cuff

One of the functions of RC, together with passive stabilisers, the ligaments, is to maintain proper stability in the shoulder joint. [29] The RC has a stabilising role, mainly in the lower ranges during arm movements, the SSC is important in anterior stabilisation. [30] The SSC and LHBT have a role in inferior stabilization. [31] The ligaments have a primary stabilizing role in arm elevation above 45°. [32]

However, another important function of the RC is the permanent centralization of the humeral head, which provides a stable pivot point during arm movement, and thus, in conjunction with the deltoid muscle, plays a crucial role in arm elevation. [33] This result is achieved through force couples. We distinguish between force couples located in the coronal and transverse planes. The force couples are shown in Figure 3.

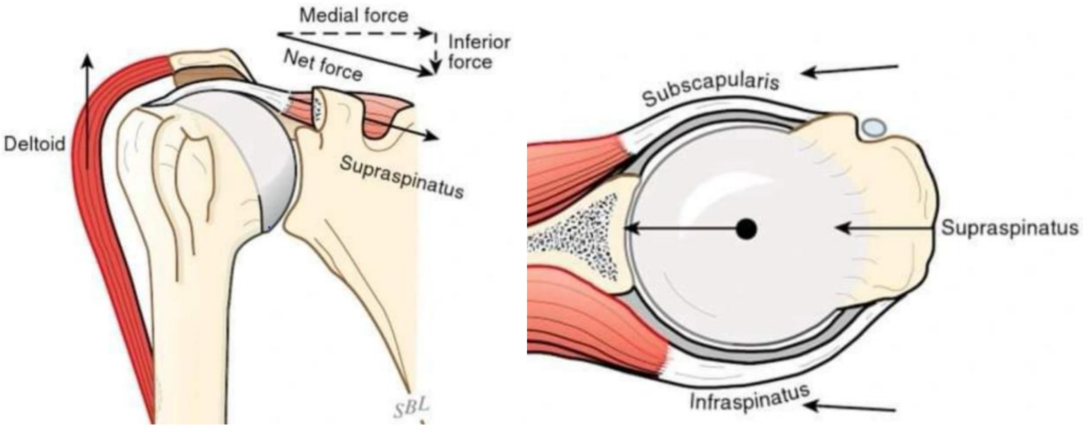

Figure 3. Left image with the force couple in the coronal plane, formed by the deltoid muscle and the SSP. Right image: transverse force couple with SSC and ISP. [34]

Cadaver studies have demonstrated that the glenohumeral (GH) joint movement remains intact as long as these fource couples are properly functioning and that the SSP is important mainly for the initiation of abduction. In the case of absence or dicreased function of the SSP, a greater load is placed on the middle portion of the deltoid muscle, which can increase the load up to 101% at the initiation of abduction and then decrease to 12% at the maximum height of the full lift. [35] Quantitative measurement studies have demonstrated that there is no significant difference in the magnitude and direction of reaction forces in the case of partial or complete rupture of the SSP compared to shoulders with intact RC. [36]

In terms of the biomechanics of the RC, we can therefore say that the transversal force couple is the main force that maintains function and muscle strength. While the coronal force couple rather plays an important role in the initiation of abduction movements.

1.1.3. Types of rotator cuff tears

There have been several studies on the classification of RC total rupture. [37] The purpose of the classification is to describe the rupture as accurately as possible in 3D. Thus, in general, more classifications are used simultaneously to describe the morphology of the rupture. In practice, the classification of the torn tendons in the sagittal plane in centimetres or in number of torn tendons is most applicable (Table 3.). [38, 39]

Table 3. Cofield classification, the RC tear in the sagittal plane expressed in centimetres.

small	less than 1 cm
medium	between 1 and 3 cm
large	between 3 and 5 cm
massive	greater than 5 cm

The retraction of the tendon is examined in the frontal plane, and from this the reconstruction possibilities are deduced (Figure 4.). [40]

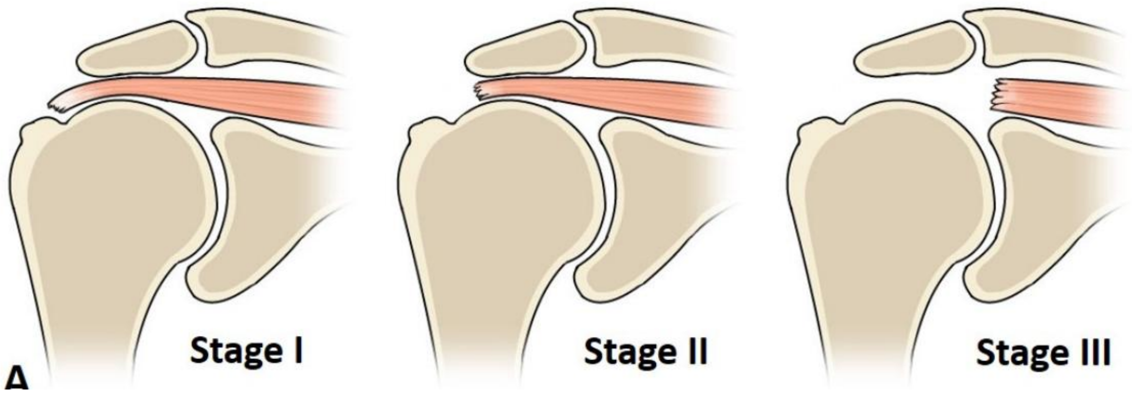

Figure 4. Patte classification, stage I: complete rupture without retraction, stage II: complete rupture with retraction to the middle of the humeral head, stage III: complete rupture with retraction to the level of the glenoid. [40]

The shape of the tears also plays an important role in preoperative planning, facilitating and expediting surgery, and has a prognostic factor (Figure 5). [41]

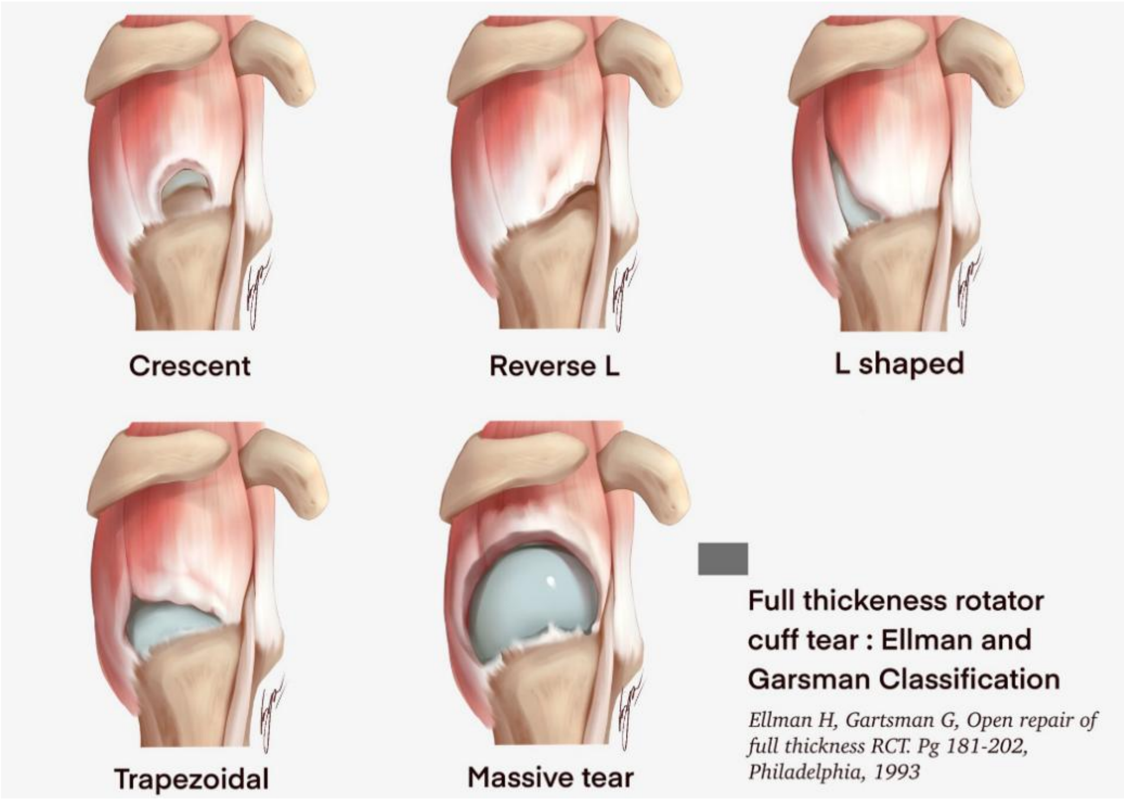

Figure 5. Full thickness rotator cuff tear shapes. [42]

1.1.4. Physical examination of the rotator cuff

The physical examination of the RC is a very important factor in the diagnosis of shoulder complaints. There are several tests for evaluating the RC [43], with different sensivity and specificity (Table 4.). [44] Of note, accurate learning and execution of the tests have a major impact on their relevance.

Table 4. Most commonly used RC tests and their sensitivity and specificity.

Tests	Sensitivity %	Specificity %
SSP		
Jobe test		
Itoı et al [45]	77	68
Jain et al [46]	88	62
Full can test		
Itoı et al [45]	77	74
Jain et al [46]	70	81
ISP		
Resisted external rotation with the elbow at the side flexed at 90		
Litaker et al [47]	76	57
External rotation lag sign		
Hertel et al [48]	70	100
SSC		
Lift off test		
Hertel et al [48]	62	100
Weakness in active internal rotation		
Hertel et al [48]	97	96
Bear-hug		
Kilic et al [49]	46	83
Belly press		
Kilic et al [49]	23	93

Newer tests include the Champagne toast test, which has been shown by EMG studies to be better at isolating SSP function than the Jobe test, but its sensitivity and specificity are not yet defined. [50] As previously discussed, the accuracy of clinical tests varies considerably, so it is advisable to combine tests of a given RC muscle test to obtain the most reliable results. [51]

1.1.5. Diagnostic imaging of the rotator cuff

In addition to physical examinations, imaging studies are essential to accurately identify the location, size and shape of the tear and the fatty infiltration of the muslce. Among our current diagnostic options, MR arthrography, native MRI and ultrasound are most commonly used.

MR arthrography has the highest specificity and sensitivity in the diagnosis of complete and partial RC tears [52] however, in the everyday practice, it is the most difficult of the three examinations to access. In a comparison of MRI and ultrasound, no significant difference in either sensitivity or specificity in the diagnosis of RC tears could be identified. [53] On the other hand, ultrasound examination is the less capable of identifying degenerative abnormalities of the muscles, such as fatty infiltration, which factor is crucial in surgical planning. Thus, ultrasound is well suited and even recommended for the diagnosis because it is easy to use and low cost and can be used to perform dynamic testing. [54] Nevertheless, considering that it is not suitable for the diagnosis of intra-articular pathology or fatty infiltration of the rotator muscles, it is recommended to perform MRI for surgical planning. [55] After RC reconstruction, however, ultrasound is an excellent tool to follow up the reconstruction, and equivalent to MRI. It is important to note that possible changes in tendon structure after reconstruction should be known so as not to misinterpret them. It is also important to note that, due to the dynamic nature of the examination, possible hardware problems such as anchor breakage or allograft displacement can be also well detected by ultrasound. [56]

1.2. The scapula and structure of the „scapulothoracic joint"

The scapula lies on the posterolateral surface of the chest wall between the 2nd and 7th ribs [57], it is triangular in shape and has three distinct edges (superior, axillary and vertebral) and three angles (superomedial, inferior and lateral). [58] Its bony connection to the chest is only through the AC and SC joints, otherwise it is attached to the chest wall by muscles only. This connection is called the scapulothoracic „joint”. Not counting the

RC muscles, the coordinated action of a total of 13 periscapular muscles results in the movement of the scapula in the scapulothoracic „joint". There are also bursas between the chest wall and the scapula, which help the scapula to move over the bony rib cage.

1.2.1. Physiological movement of the scapula

When the arm is lifted, the RC and scapula are in coordinated motion. In the initial stages of the lift, the humerus rotates relative to the scapula, and in the subsequent stages of the lift, scapular rotations are involved. Alternatively, at higher lifting angles, the rotational movement of the scapula is also involved through the AC joint around the clavicle and then through the SC joint in relation to the bony chest wall. All of the above movements are required to achieve 180° of arm lift. During the lifting process up to 120°, the majority of the process occurs in the GH joint. Beyond this point, movement is inhibited in the GH joint as the humerus collides with the acromion and subsequent upward rotation of the scapula assists in lifting between 120 and 180°. [59] This coordinated action of the scapula and humerus is called scapulohumeral rhythm (SHR). The ratio of GH to ST articualtion during the total lift is 2:1. [60]

The position of the scapula on the chest wall is as follows, with an internally rotated position of approximately 30° in the horizontal plane (protracion), an abducted position of 3° in the frontal plane (upward rotation) and a forward position of 20° in the sagittal plane (atnerior tilting). [61] In addition to the SHR mentioned above, the following scapular rotations occur during arm elevation (Figure 6.):

1. protraction (internal rotation) - retraction (external rotation) in the horizontal plane
2. anterior tilting - posterior tilting in the sagittal plane
3. upward rotation - downward rotation in the frontal plane.

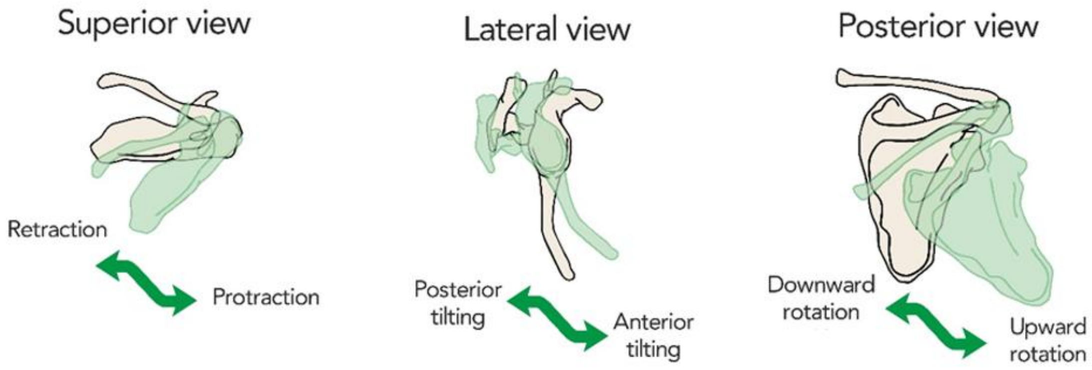

Figure 6. Scapula rotations. [62]

When the arm is raised under physiological conditions, retraction, posterior tilting, and upward rotation of the scapula occur. Based on biomechanical measurements, the average displacements during 180° of arm flexion are 24° of retraction, 30° of posterior tilting, and 50° of upward rotation. [63]

1.3. Scapula dyskinesis, types

The abnormal changes in scapular movement and function are collectively referred to as scapular dyskinesis. Alternatively, according to the newer terminology, it is referred to as scapulothoracic abnormal motion (STAM). [64] The etiological spectrum can be extremely diverse. Today, there are two main classification systems in use for SD evaluation.

1.3.1. Kibler classification

The Kibler classification focuses primarily on morphological changes. It does not determine exactly the underlying etiology and does not provide accurate therapeutic recommendations for the detected abnormalities. The presence of SD is most commonly identified during forward flexion of the arm (sagittal flexion). [65] According to the standard classification, three types of SD can be distinguished:

Type I.: a posterior displacement from the thorax of the inferior medial angle of the scapula,

Type II.: a posterior displacement from the thorax of the entire medial border of the scapula,

Type III.: an early scapular elevation or excessive scapular upward rotation during dynamic observation (Figure 7.).

Figure 7. Scapula dyskinesis (Kibler classification): A: Type I., B: Type II., C: Type III. [66]

According to this classification in SD, proximal and distal causative factors can be observed. Proximal factors may include the weakness of the periscapular muscles, lower trapezius, and serratus anterior, while distal factors may include joint internal problems such as labral tears, GH instability, rotator cuff pathology, acromioclavicular separation. [67, 68] Proximal factors are usually manageable with rehabilitation, while distal ones often need a surgery followed by proper rehabilitative protocols.

1.3.2. STAM classification (Elhassan)

Elhassan introduced the new nomenclature, scapulothoracic abnormal motion (STAM). This classification identifies the etiological background more accurately and, accordingly, offers precise therapeutic treatments. The first part of this classification determines changes in the functioning of the periscapular muscles. [64]

STAM 1.:

It is characterized by hyperactivity of the pectoralis minor, resulting in minimal STAM, anterior tilt of the scapula, and tenderness at the pectoralis minor insertion, alongside hyperactivity of the upper trapezius.

STAM 2.:

2A: It involves more pronounced STAM, hyperactivity of the pectoralis minor, and underactivation of the serratus anterior. The condition can be corrected by manual maneuver.

2B: This can also be characterized by hyperactivity of the pectoralis minor and underactivation of the serratus anterior. Manual correction is more challenging.

STAM 3.: musculus serratus antarior paralysis

Serratus anterior paralysis is a well-known problem associated with long thoracic nerve palsy.

STAM 4.: musculus trapezius paralysis

The underlying cause is predominantly the damage of the accessory nerve.

STAM 5.: musculus serratus anterior and musculus trapezius dysfunction

This dual disorders result in a more pronounced STAM due to the critical roles both muscles play in stabilizing and facilitating movement of the scapula. Despite significant damage, the position of the scapula in STAM 5 can often be corrected manually.

STAM 6.:

Trapezius and serratus anterior paralysis lead to a condition where the scapula is “locked” in a position. While the abnormal position appears fixed and irreversible when conscious. It can be reversed under anesthesia, suggesting that muscle spasms or tension may contribute to the fixed position of the scapula.

STAM 7.: dancing scapula

7A: „Dancing Scapula with Activity" a response to voluntary shoulder or arm movements. Abnormal movement of the scapula is triggered or exacerbated by certain movements, suggesting a reactive pattern related to muscle activity or movement of the shoulder girdle.

7B: „Spontaneous Dancing Scapula" refers to involuntary scapula movements that occur without any apparent cause or voluntary shoulder movement. This pattern of scapula movement indicates a more complex neuromuscular problem.

The second part of the classification provides precise therapeutic recommendations for each classification, including detailed descriptions of the necessary surgical procedures. [69, 70] The detailed treatment protocol is shown in Figure 8.

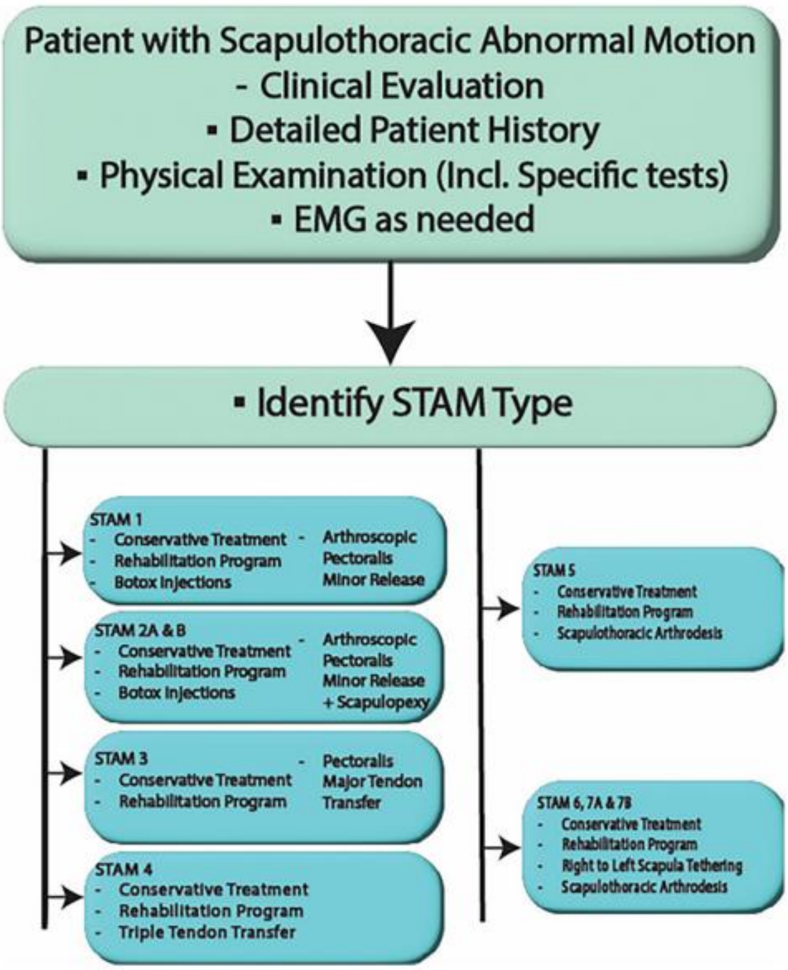

Figure 8. Treatment flowchart for STAM subtypes. [64]

1.3.3. Scapula dyskinesis in rotator cuff tear

Reviewing the literature, SD is very common in all kinds of shoulder pathology, let it be RC pathology, impingement syndrome, GH instability, AC pathology, labral tears. [71-74] Based on the above, it can be seen that SD in rotator cuff tears mainly can be placed in STAM 1 and 2, the affected periscapular muscle pattern can be determined. SD is primarily characterized by hyperactivity of the pectoralis minor and upper trapezius, as well as hypoactivity of the serratus anterior. But the exact causal background is still not clear in RC pathology. Does rotator cuff pathology and pain cause SD, or does SD causes rotator cuff pathology and pain?

1.4. Physiotherapy management of SD

If scapula dyskinesis is present in RC tear or after RC reconstruction, special attention should be paid to its treatment during rehabilitation. Rehabilitation should be guided by the muscular pattern differences described above. The aim of SD treatment is to restore the retraction and posterior tilt of the scapula.

Flexibility exercises: to increase the flexibility of the pectoralis minor muscle and the external rotation and posterior tilt of the scapula. [75, 76]

Stabilizing exercises with stretching and strengthening to optimize scapula movement and improve muscle strength and joint position awareness. [77, 78] Closed and open kinetic chain exercises, including push-ups and resisted scapular retraction. [78]

The serratus anterior and trapezius muscles play a key role in stabilizing the scapula. They act as a fource couple during upper limb movements and are particularly important in the position above the head. [79, 80] The push-ups on a stable surface stretch the serratus anterior and improve the general muscle strength. The push-ups on an unstable surface increase the trapezius activation while decreasing the serratus anterior activation. [81]

2. Objectives

As we have seen from the reviews, SD is present in a high percentage of shoulder pathologies. It can occur in the absence of shoulder complaints, but in this case its clinical relevance is much less. The existence of the numerous etiological backgrounds such as RC tear, AC complaint, impingement syndrome, instability, etc., it is impossible to investigate all of them simultaneously. Therefore, in our study, we focused on SD occurring along with RC tear, which is the highest percentage shoulder problem affecting the society. Up to this day, it is still undetermined whether the tear and/ or the pain trigger SD or SD triggers the tear and/or the pain in RC.

The aim of our study was to compare the scapulothoracic movement pattern of people with a similar rotator cuff tear pattern (medium size tear) to the scapulothoracic movement pattern of healthy people. We also examined the post-treatment status of the tear and compared it with the pre-treatment status. Our goal was to answer questions about the factors that most influence scapular motions. Furthermore by changing these factors how will scapular motion change and how will the functional operation of the shoulder joint change?

2.1. Objective I. – Valid 3 D upper limb motion analysis

In the first step of our study, we performed the validation measurements and applied the settings that made the laboratory tool previously used for lower limb motion analysis suitable for upper limb 3D motion analysis and accurate data acquisition.

Specific questions:

1. Are our values of the scapula rotational deviations verified in the measurements consistent with the results reported in the international literature?

2.2. Objective II. – The role of pain in SD in cases of RC tears

The second aim of our study was to determine what plays the primary role in the development of SD in RC rupture, the pain or the rupture itself?

Specific questions:

1. If the pain is reduced or eliminated by non-surgical treatments (i.e. Lidocaine injection), will the SD improve or disappear?
2. Does SD trigger pain, or does pain trigger SD?
3. Is there an improvement in function if pain is eliminated?

2.3. Objective III. – Benefits from RC reconstruction

The third aim of our study is to assess the benefits of arthroscopic RC reconstruction in medium sized, full thickness cuff tear.

Specific questions:

1. Does the presence of SD change after surgery?
2. Is there an improvement in shoulder joint function in terms of ROM and muscle strength after surgery?
3. Is 6 months of rehabilitation after RC reconstruction in general sufficient to restore shoulder function in terms of pain, ROM, muscle strength and SD?

2.4. Objective IV. – Rehabilitation, SD directions

The fourth aim of our study was to try to identify clearer SD guidelines, taking into account the literature and our own reults, to guide rehabilitation in non-operative or post-operative cases.

Specific questions:

1. Are the SD deviations and directions the same for all RC tears, regardless of the size of the tear?

3. Methods

3.1. Participants

Our study was a prospective, monocentric study conducted between September 2020 and September 2022. Our work was approved by the Regional, Institutional Scientific and Research Ethics Committee SE RKEB 90/2020. All subjects gave written informed consent. The site of our study was the Gait Analysis Laboratory of the Department of Orthopaedics at Semmelweis University, a laboratory for biomechanical measurements. The subjects were divided into 2 groups. The healthy group (HG) consisted of 9 volunteers who never had any shoulder complaints or shoulder injuries. An ultrasound scan by radiologist (Samsung HS 60, 16 MHz linear head) was performed to exclude possible rotator cuff and AC joint pathology. Indeed, Yamaguchi's study showed that a high percentage of rotator cuff pathology involved the other shoulder of the subjects. Therefore, we chose as a control group people with no previous shoulder as a control group rather than the other shoulder. [82]

We also included 9 people in the surgical group (SG) who had a moderate (1-3 cm) full-thickness rotator cuff tear confirmed by MRI. They had persistent pain despite conservative treatments (physiotherapy, NSAIDs) and were therefore scheduled for rotator cuff reconstruction surgery. Among these patients, MRI scan confirmed fatty infiltration with Goutallier I in 7 cases and Goutallier II in 2 cases. Patient selection exclusion criteria included cervical radiculopathy, glenohumeral instability, previous shoulder fracture, muscular dystrophy, previous stroke, symptomatic AC arthritis, rheumatoid arthritis, previous shoulder surgery. Patient demographics are shown in Table 5.

Table 5. Patient demographic data. Age and BMI values of HG and SG groups were compared. HG: healthy group, SG: surgery group, SD: standard deviation. Two-sample t-test was used to calculate the P value. [62]

	HG	SG	*P* value
number of patients	9	9	-
male/female	7/2	3/6	-
Age (mean ± SD)	57.6 ± 9.8	59.2 ± 7.8	.950
dominant side right/left	7/2	7/2	-
affected side right/left	7/2	8/1	-
BMI (mean ± SD)	28.4 ± 3.4	28.7 ± 3.0	.748

3.2. Surgical procedure

All surgeries were performed by the same surgeon (GS). General anaesthesia and interscalene blockade were used during the surgeries. The procedures were performed in beach chair position. Arthroscopic (Arthrex, Synergy 4K, Naples, FL, USA) single row rotator cuff reconstructions were performed with implantation of one or two anchors (Corkscrew 5.5 mm Ti FT III anchor, Arthrex, Naples, FL, USA). These tear sizes showed no difference in postoperative outcomes when comparing single row, double row and transosseous equivalent techniques. [83, 84] The arm was sling fixed for 6 weeks postoperatively. Passive and assisted active physiotherapy exercises under the guidance of a physiotherapist were started by the patients on the first postoperative day. Active movements and muscle strengthening exercises were started after the 6th week, also under the supervision of a physiotherapist.

3.3. Biomechanical outcome collection

The examination were carried out in sitting position. All participants were subjected to the same measurement protocol. Subjects were asked to raise their arms in the sagittal plane three times, starting at their sides, to the maximum height they could, and then lower them. Rotational movements of the scapula during sagittal flexion of the humerus were also analysed on all three occasions for all participants. The mean value of the results was used for the calculations. The primary purpose of these arm raises and lowers was to determine the scapula rotation values. However, as a secondary objective, we were also able to simultaneously assess the values of humerus sagittal flexion.

Motion analysis and assessment of both groups (HG and SG) was performed with the VICON motion capture system (Nexus 2.10, Oxford Metrics, Oxford, UK). Patients in the SG group were subjected to the measurement process three times. The first two measurements were taken on the same day. The time between the first two measurments and surgery was 87.3±20.9 days.

1. Before surgery, without any medication (before surgery native subgroup - BSN),
2. Before surgery, 10 minutes after landmarked-based administration of 10 ml of 1% Lidocaine solution (EGIS, Hungary) into their subacromial space (before surgery injection subgroup - BSI),
3. Six months after surgery (after surgery subgroup - AS).

Patients in the SG group received physiotherapy after surgery. In addition, 6 months after surgery, all patients underwent ultrasound examination by radiologist (Samsung HS 60, 16 MHz linear head) to confirm the integrity of the rotator cuff.

3.4. Laboratory

Our measurments were carried out at the Gait Analyis Laboratory of the Department of Orthopaedics of Semmelweis University (Figure 12.).

Figure 12. Photographs of the gait analysis laboratory with wall-mounted infrared cameras.

For our study, we used a VICON motion capture system equipped with 7 infrared cameras, 6 of which are MX T40 and 1 standalone Vantage 5. In addition to the infrared cameras, 2 additional cameras are available to capture the actual visual image of the measurement (Figure 13). In many cases, by reviewing these images we could detected our initial errors, which in most cases were due to inadequate marker fixation and consequent displacement.

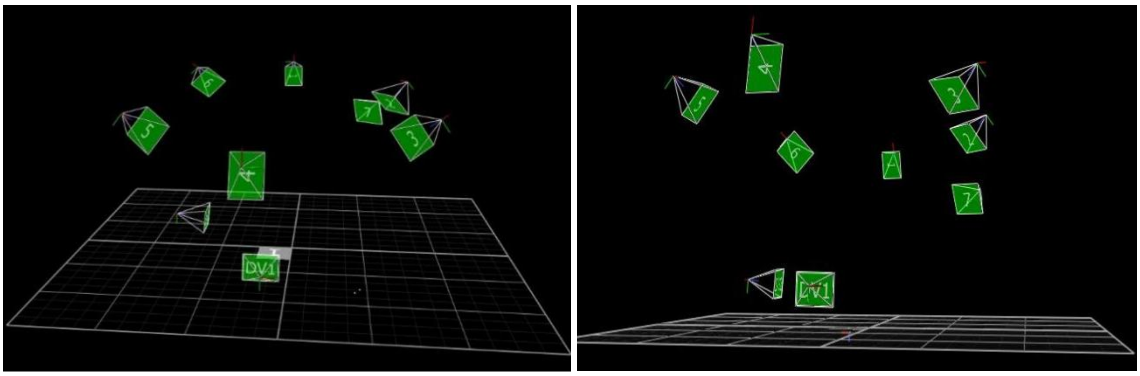

Figure 13. VICON system architecture of the lab. The grey 1 mark shows the location of the person being tested. Green 1-7 indicate the position of the infrared cameras, DV1 and DV2 indicate the cameras recording the real images (left image top and right image side view). [85]

3.5. Physical markers

Scapular examination is cumbersome due to the fact that it is thickly covered with muscle, and as a result it is often difficult to place markers because the scapula moves on a large area under the skin surface, so some of the surface markers would give inaccurate results. Previous studies have attempted to use fixed markers, either by means of sensors mounted on Kirschner-wires drilled into the body of the scapula [86] or by means of scapula tracking devices [87] glued to the skin surface above the scapula to model the scapula skeleton. Although measurements taken with these devices have shown valid results, they have not been widely used due to painful or even heavy application and difficulties in calibration. The VICON system at Semmelweis University's Gait Analysis Laboratory uses cameras to detect markers in the infrared range. These markers are actual physical markers that are attached to specific points on the body of the subjects under investigation (Table 6.).

Table 6. Physical marker placement and marker structure. [85]

Marker placement	**Marker structure**
sternum	tripartite marker
acromion top	tripartite marker
outer side of the upper arm	quadripartite marker
extensor site of the forearm	quadripartite marker
under the chair	tripartite marker

In some regions, different numbers of markers were used and placed on plastic sheets for more secure fixation and more reliable infrared capture (Figure 14.).

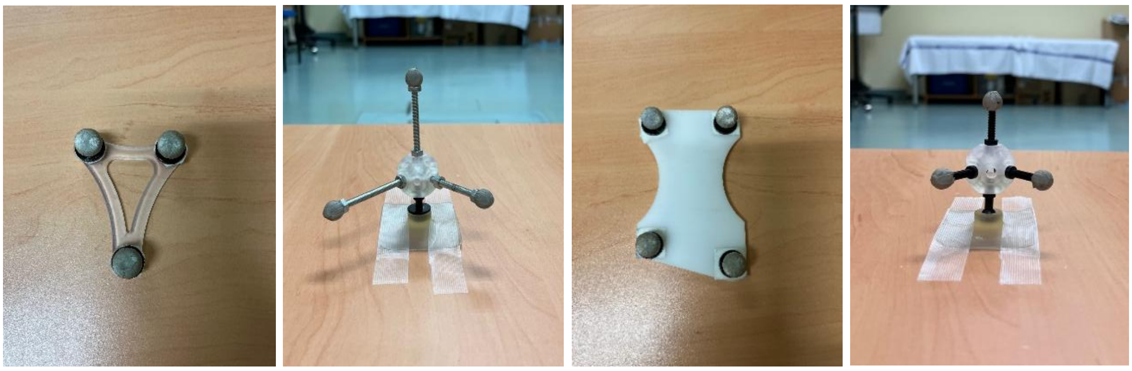

Figure 14. Marker structure from left to right. Tripartite placed on sternum, tripartite placed on top of acromion, quadripartite attached to upper arm and forearm area, tripod placed under chair.

These plastic sheets were fixed to the patients with Peha-haft 8 cm x 4 m self-adhesive tape and Omnifilm 2.5 cm x 5 m adhesive tape. These elements are applied all over the body and are detected by the cameras in the infrared range (Figure 15.)

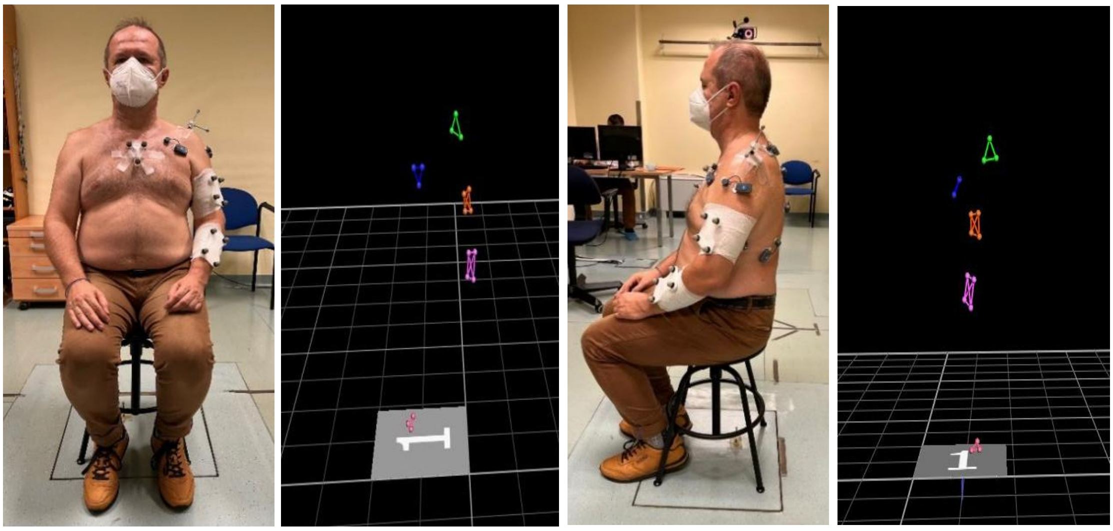

Figure 15. State after the physical markers have been applied. Marker placement on the sternum, above the acromion, on the upper arm and forearm, and also marker placement under the chair (EMG electrodes are visible next to the real markers) from front and side views. The digital images show the real markers detected by VICON from the front and side view (17 markers). [85]

3.6. Calibration markers

In upper limb motion analysis, it is also important to standardise protocols so that the results can be compared in the future. [88] The development of the informatics background for upper limb motion analysis started in the second half of the 2000s. The result of this development was the software of Upper Limb Evaluation in Motion Analysis (ULEMA). [89] It is a method for the analysis of 3D kinematics of the upper limb based on the detection of physical markers placed all over the body and the identification of virtually recorded calibration points. ULEMA runs on and performs its calculations using MATLAB R2010a or higher. The kinematic calculations for the upper limb are based on the rigid body model assumption by assigning local coordinate systems to each segment (trunk, scapula, upper arm, forearm, hand). The software uses International Society of Biomechanics (ISB) guidelines for the calculation of anatomical coordinate systems and joint angles (trunk, scapulothoracic joint, shoulder, elbow, wrist). [90] The protocols can be modified to suit the desired measurement practices. The open source code allows for further development and task specialisation of the software. The software is available online (GitHub: https://github.com/u0078867/ulema-ul-analyzer). As I mentioned in addition to the physical markers, the ULEMA also requires the inclusion of calibration markers. Calibration markers are virtual markers (Table 7.).

Table 7. Names of calibration markers and their anatomical location. [85]

1.	calEL (epicondylus lateralis, elbow)
2.	calEM (epicondylus medialis, elbow)
3.	calUS (ulnar styloid, wrist)
4.	calRS (radial styloid, wrist)
5.	calAA (angulus acromialis, scapula)
6.	calTS (trigonum scapulae, scapula)
7.	calPS (processus coracoideus, scapula)
8.	calAI (angulus inferior, scapula)
9.	calAC (acromioclaviculer joint, AC joint)
10.	calIJ (internal jugulum, sternum)
11.	calPX (processus xiphoideus, sternum)
12.	calC7 (C 7 cervical vertebra, spine)
13.	calT8 (Thoracic 8 vertebrae, spine)
14.	GHr (glenohumeral rotation, centre of rotation of the shoulder)

They are recorded using a special marking stick, also equipped with physical markers. The markers on the stick are not equally spaced apart (Figure 16.). This stick is used to point to the positions of the calibration markers (Figure 17.).

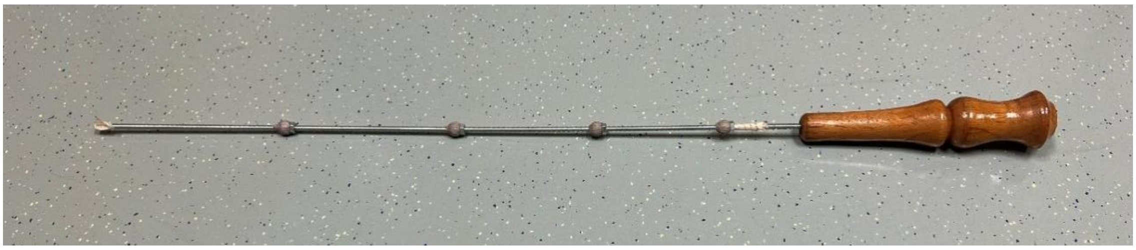

Figure 16. Marker stick used to record calibration points.

Figure 17. Recording calibration points. Left calC7, right calAC. Physical markers highlighted in colour.

When recording the position of the calibration markers, the ULEMA software compares the position of the calibration markers to the physical markers placed around the body and to the physical markers on the stick. During the arm raising and lowering exercises of the subjects, the change in the position of the physical markers is detected by VICON, while the changes in the position of the calibration markers are calculated by the ULEMA algorithms. Thus a total of 31 points are recorded for each measurement, 17 physical markers and 14 calibration points (Figure 18.).

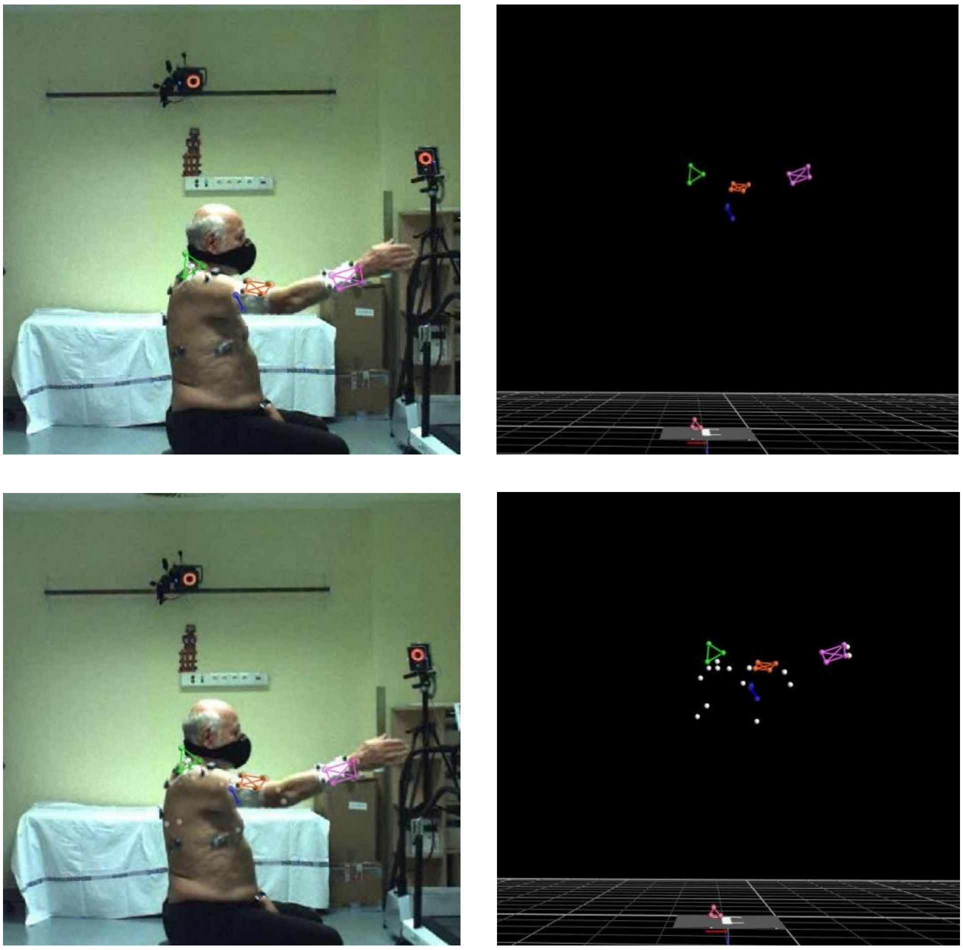

Figure 18. Top left image is the live image captured by the cameras, with the physical markers detected by VICON, top right image is the version displayed by VICON.

Bottom left image is the live image captured by the cameras showing all the physical and calibration markers detected by the VICON and ULEMA system in cooperation. Bottom right image is the version displayed by VICON with all the physical and calibration markers, 31 in total. [85]

3.7. Clinical outcome collection

In the SG group, the Constant - Murley (CM) score, the American Shoulder and Elbow Score (ASES) and the OXFORD Shoulder score were used to objectify quality of life and functional outcomes. [91] As described previously, the VICON and ULEMA systems were used to assess sagittal flexion of the arm also. To measure the muscle strength of the RC we used a dynamometer (SDF-300, China). To assess pain we used the visual analog scale (VAS).

Muscle strength was measured in each subgroup (SG consists of BSN, BSI and AS subgroups) during Jobe test, bear-hug test and by external rotation in next-to-the-body position using the dynamometer (Figure 19.).

Figure 19. From left to right. The first picture shows the dynamometer. The second picture illustrates the measurement of the external rotation force, the third picture depicts the force measurement during the Jobe test, and the fourth picture shows the measurement during the bear-hug test. [85]

Maximal sagittal flexion was measured by asking the participants to lift their arms in the sagittal plane starting from their side to the maximum height they could reach, three times in succession.

3.8. Measurement of scapula movements

The following 3D kinematic parameters of the shoulder girdle were analysed: sagittal flexion/extension of the humerus (+/-), scapular protraction/retraction (+/-), scapular anterior tilt/posterior tilt (+/-), scapular upward/downward rotation (+/-) (Figure 20.). Scapular motion during sagittal flexion and extension of the humerus was investigated. Patients in the BSN subgroup were able to raise their arms to an average of 114°, so scapular motion during arm raising was assessed to be between 20° and 110°. The values of scapula rotations in sagittal flexion of the humerus were analysed every 10° in each group and subgroup (HG, BSN, BSI, AS).

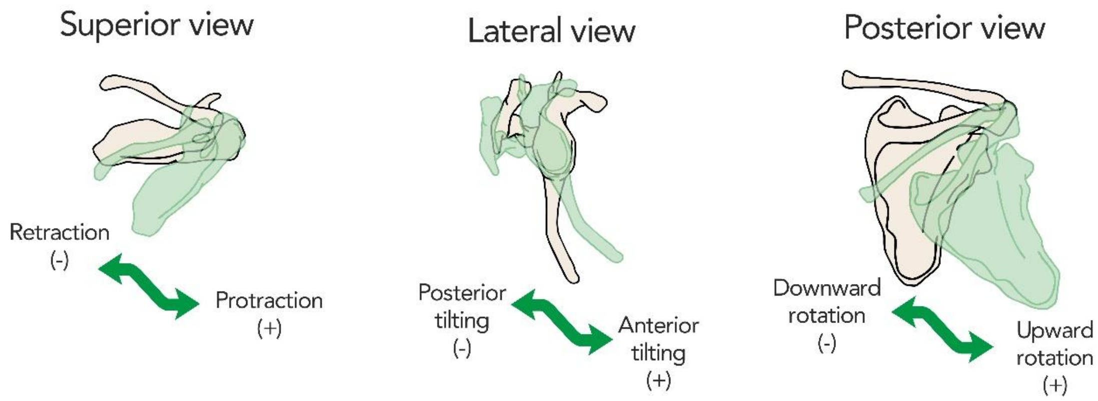

Figure 20. Scapula rotations with display of directions. [62]

3.9. Statistical analysis

Before statistical analysis, the normality of all data was tested using the Lilliefors test. For scapular rotations a significant proportion of the data failed the normality test at each of the 10° of sagittal flexion of the humerus. In order to treat all cases uniformly and due to the presence of outliers, scapula angles of HG and BSN groups were analyzed with a Wilcoxon rank-sum test. Similarly, Wilcoxon signed rank test was used to compare the scapula angles of the BSN-BSI and BSN-AS subgroups. Bonferroni correction was used for the statistical tests of BSN-BSI, and BSN-AS and therefore the level of statistical significance was set at $P<0.025$.

Scores and maximal sagittal flexion of HG and BSN subgroup passed the normality test and the two-sample F-test successfully; therefore, they were analyzed with two-sample t-test. Muscle strength data of HG and BSN groups were compared with Wilcoxon rank-sum test, since they failed the normality test.

The functional scores and quality of life outcomes, muscle strength, maximal humeral sagittal flexion and VAS score of the three subgroups (BSN, BSI, AS) studied successfully passed the test of normality, and a paired t-test was used to detect differences between the muscle strength, maximal humeral sagittal flexion and VAS score of the BSN-BSI and BSN-AS subgroups.

The calculations were performed using the MATLAB R2020b program. Continuous variables are expressed as mean ± SD.

4. Results

4.1. Comparison of HG group – BSN subgroup

In the first part of our work, we examined the BSN subgroup where patients did not receive injections or surgical care. It was compared to the HG group.

4.1.1. Scapular movements

We compared scapular rotation values during humerus sagittal flexion between the HG and BSN groups, both during arm raising and lowering. Increased protraction has been detected in BSN subgroup both in the raising and lowering phases but the change did not reach the level of significance. No significant difference in anterior/ posterior tilting and upward/ downward rotation movements was confirmed in either the raising or lowering phases (Table 8.). The results are shown in Figure 21., with HG in black and BSN subgroup in red.

Table 8. Statistical results of deviations in scapula rotations during arm raising and lowering, HG group – BSN subgroup comparison.

Significant differences (*P*<0.025)

dgr: degree, HG: healthy group, BSN: before surgery native subgroup, scap. proret.: scapula protraction/ retraction, scap. a/p tilting: scapula anterior/ posterior tilting, scap. up/dn rot.: scapula up/ down rotation

HG - BSN							
Arm raising				Arm lowering			
dgr	scap. proret. *P*	scap. a/p tilting *P*	scap. up/dn rot. *P*	dgr	scap. proret. *P*	scap. a/p tilting *P*	scap. up/dn rot. *P*
20°	.113	.258	.796	110°	.240	1.00	.518
30°	.063	.258	.730	100°	.328	.607	.388
40°	.063	.258	.489	90°	.224	.529	.456
50°	.077	.258	.340	80°	.167	.815	.963
60°	.094	.222	.340	70°	.094	.666	.796
70°	.139	.236	.481	60°	.113	.489	.796
80°	.328	.328	.955	50°	.136	.436	.796
90°	.388	.529	.864	40°	.113	.387	.796
100°	.240	.898	.699	30°	.136	.436	.863
110°	.240	1.00	.606	20°	.113	.436	.730

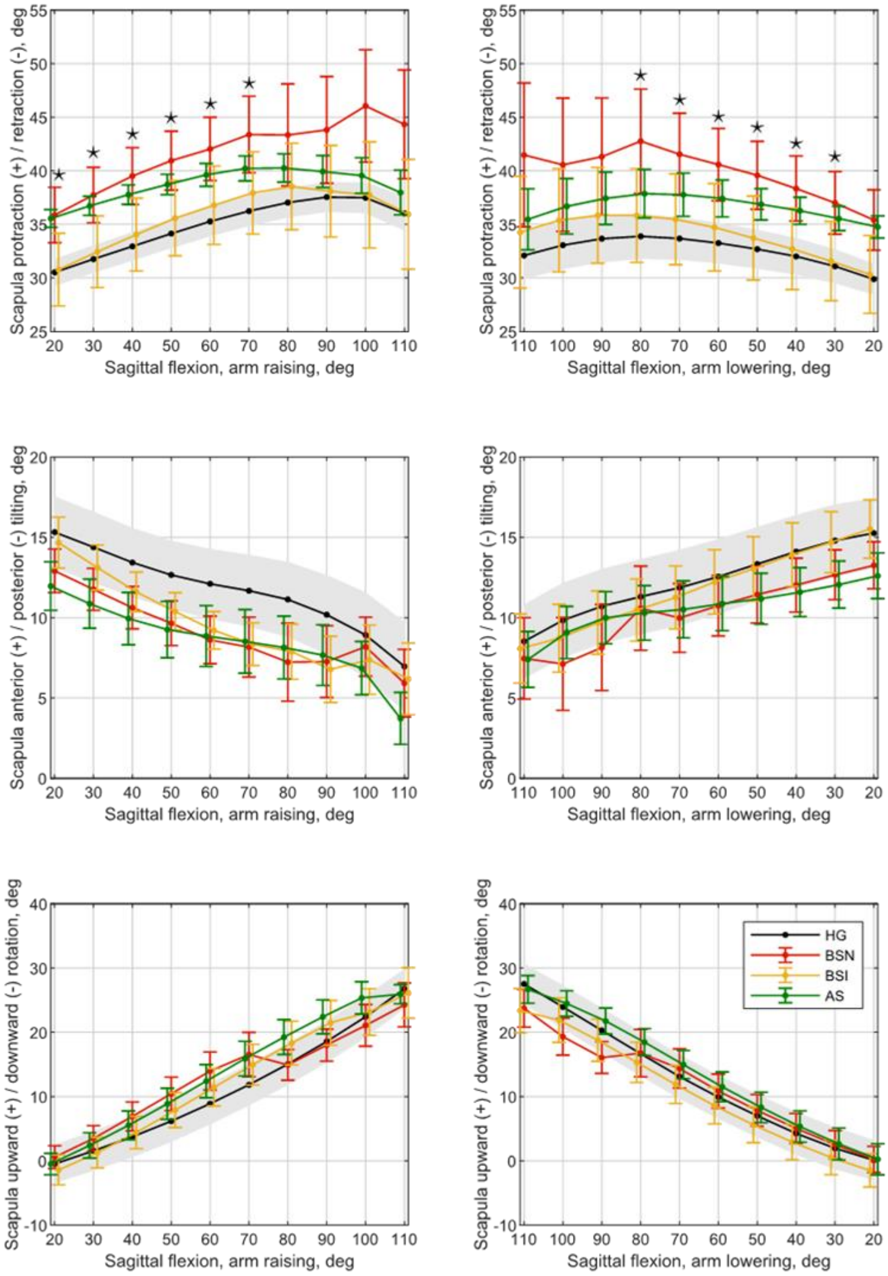

Figure 21. Mean curves of angular values of scapular rotations during raising and lowering of the arm in the sagittal plane. [62]

Black, red, yellow, and green color stands for HG and BSN, BSI, AS subgroups, respectively. Colorful error bars show the standard error of the corresponding group/subgroup. The upper and lower band of the grey shaded area indicate the standard error of the HG group. Statistically significant difference ($P<0.025$) between BSN and BSI subgroups are denoted by *. Matlab R2020b and Inkscape were used to create the figure.

4.1.2. Functional scores and quality of life outcomes

Oxford, ASES and CM scores were significantly higher in the HG than those of the BSN subgroup (Table 9.).

Table 9. Comparison of HG and BSN subgroup score, muscle strength, and maximal sagittal flexion.

Significant differences (*P*<0.025) are marked with *.

Data of score, muscle strength, and maximal sagittal flexion are given as mean±SD. HG: healthy group, BSN: before surgery native subgroup, SD: standard deviation

	HG	BSN	*P* value
Oxford score	47.6±0.9	27.7±10.2	**<.0001***
ASES score	99.1±1.4	46.7±19.3	**<.0001***
CM score	89.3±2.4	48.2±17.3	**<.0001***
Jobe test (N)	61.7±9.7	32.0±18.2	**<.0001***
bear-hug test (N)	70.1±18.2	64.9±16.9	.537
external rotation force (N)	52.8±11.9	34.2±11.1	**.004***
humerus maximal sagittal flexion (deg)	151.1±13.8	114.7±33.5	**.005***

4.1.3. Strengths of the rotator cuff

Significantly higher muscle strength was observed in the HG group compared to the BSN subgroup in the Jobe test and external rotation, the differences were 29.7 and 18.6 Newton, respectively. No significant difference was observed during bear-hug test (Table 9.).

4.1.4. Maximal sagittal flexion

Significantly higher maximal flexion was observed in the HG group compared to the BSN subgroup (Table 9.), the difference was 36.4°, standard deviation can not be interpreted since the two groups (HG and BSN) involve different subjects.

4.2. Comparison of BSN – BSI and BSN – AS subgroups

In the second part of our study, we analysed the subgroups of the SG group. We examined the effect of injection and surgery by comparing the BSN - BSI subgroups and BSN - AS subgroups.

4.2.1. Scapular movements

In the further investigation of our study, we compared the scapular movements of the different subgroups of the SG group (BSN and BSI, BSN and AS) during arm raising and lowering.

When comparing the BSN and BSI subgroups, we observed a significant difference in scapular protraction in the lifting phase between 20° and 70° (Table 10.). The mean decrease in protraction was 5.3° in the BSI group, with a mean of standard deviation of 7.9° (Table 11.). Similarly, a significant difference in the arm lowering phase was observed in protraction between ranges of 80° and 30 ° (Table 10.), with a mean decrease of 6.0° in the BSI group, and a mean of standard deviation of 8.3° (Table 11.) (Figure 21.). However, no significant difference in either anterior/posterior tiliting of the scapula or upward/downward rotation of the arm during the raising and lowering phases was found in the BSI group (Table 10.)

When analyzing the BSN and AS subgroups, we also observe that the largest change occurs in the scapular protraction, i.e. the normalization of the scapular movement pattern starts towards the control group, but it does not reach the level of significance. There was no significant change in anterior/posterior tilting and upward/downward rotation (Table 10.) (Figure 21.).

Table 10. Statistical results of deviations in scapula rotations during arm raising and lowering after injection and after surgery. [62]

Significant differences (*P*<0.025) are marked with *.

dgr: degree, BSN: before surgery native subgroup, BSI: before surgery injection subgroup, AS: after surgery subgroup, scap. proret.: scapula protraction/ retraction, scap. a/p tilting: scapula anterior/ posterior tilting, scap. up/dn rot.: scapula up/ down rotation, n.s.: not significant

Arm raising							Arm lowering							
	BSN - BSI			BSN - AS				BSN - BSI			BSN - AS			
dgr	scap. proret. *P*	scap. a/p tilting *P*	scap. up/dn red. *P*	scap. proret. *P*	scap. a/p tilting *P*	scap. up/dn red. *P*	dgr	scap. proret. *P*	scap. a/p tilting *P*	scap. up/dn red. *P*	scap. proret. *P*	scap. a/p tilting *P*	scap. up/dn red. *P*
20°	**.020***	.250	.250	.652	.301	.359	110°	.063	.318	.438	.188	.625	.813
30°	**.004***	.301	.164	1.00	.426	.301	100°	.031	.442	.313	.438	.313	.313
40°	**.004***	.359	.203	1.00	.570	.359	90°	.031	.153	.563	.563	.438	.313
50°	**.008***	.426	.426	.910	1.00	.496	80°	**.008***	.683	.383	.313	.742	.148
60°	**.008***	.496	.652	.910	.910	.496	70°	**.008***	.289	.570	.301	.652	.734
70°	**.016***	.945	.742	.844	.461	.945	60°	**.012***	.076	.570	.426	1.00	.820
80°	.063	1.00	.688	1.00	.563	.844	50°	**.020***	.180	.570	.652	.910	.734
90°	.063	.438	.844	.563	.844	.844	40°	**.020***	.437	.652	.652	.910	.570
100°	.063	.813	1.00	.438	.625	1.00	30°	**.020***	.349	.652	1.00	.820	.570
110°	.063	.625.	1.00	.313	.813	1.00	20°	.039	.308	.820	.734	.734	.820

Table 11. Difference between BSN - BSI subgroups scapula protraction. [62]

Significant differences (*P*<0.025) are marked with *. *P* values are given in Table 10.

BSN: before surgery native subgroup, BSI: before surgery injection subgroup, dgr.: humerus sagittal flexion degree, SD: standard deviation, IQR: interquartile range, CI: confidence interval

BSN - BSI comparison													
	Protraction arm raising							Protraction arm lowering					
dgr	mean change	media change	SD	IQR	CI 95%		dgr	mean change	media change	SD	IQR	CI 95%	
20°	**-5.1***	**-1.1***	8.4	6.5	-11.6	1.4	110°	-2.3	-2.0	1.7	2.7	-4.4	-0.2
30°	**-5.3***	**-1.7***	8.1	5.8	-11.5	1.0	100°	-5.4	-3.1	7.2	3.6	-13.0	2.1
40°	**-5.5***	**-2.0***	8.0	5.5	-11.6	0.7	90°	-5.6	-3.4	7.2	3.3	-13.1	2.0
50°	**-5.4***	**-2.1***	7.7	5.8	-11.3	0.6	80°	**-7.2***	**-3.7***	8.4	9.2	-14.3	-0.2
60°	**-5.2***	**-2.0***	7.6	5.9	-11.4	0.6	70°	**-6.1***	**-2.9***	8.4	5.6	-12.6	0.4
70°	**-5.7***	**-2.0***	8.0	8.0	-12.4	1.0	60°	**-5.9***	**-2.6***	8.2	4.9	-12.2	0.5
80°	-3.9	-1.9	6.0	1.0	-10.2	2.4	50°	**-5.9***	**-2.8***	8.3	5.1	-12.2	0.5
90°	-4.2	-2.2	6.2	0.5	-10.7	2.3	40°	**-5.6***	**-2.6***	8.4	5.2	-12.1	0.8
100°	-1.9	-2.2	0.7	0.7	-2.8	-0.9	30°	**-5.4***	**-1.9***	8.5	5.9	-12.0	1.1
110°	-1.5	-1.6	0.7	0.8	-2.3	-0.6	20°	-5.1	-1.1	8.7	7.1	-11.8	1.6

4.2.2. Functional scores and quality of life outcomes

Comparing the score values of the BSN and AS subgroups, a significant improvement was observed in the AS group for all three scores (Table 12.).

4.2.3. Strengths of the rotator cuff

No significant improvement in muscle strength in the Jobe and external rotation tests was observed when comparing either the BSN and BSI subgroup or the BSN and AS subgroup. However, there was a significant improvement in muscle strength in the bear-hug tests in both the BSI and AS subgroups compared to the BSN subgroup (Table 12.).

4.2.4. Maximal sagittal flexion

In post-injection examinations, a significant increase was observed, with maximal sagittal arm flexion increasing by 17.77° ± 17.01° in the BSI subgroup. Also, a significant improvement was demonstrated in the AS subgroup, where an increase of 29.77° ± 28.05° was demonstrated compared to the BSN group (Table 12.).

4.2.5. Pain

Examining VAS before (BSN subgroup) and after (BSI subgroup) injection and 6 months after surgery (AS subgroup), both groups (BSI and AS) showed significant pain reduction with injection 2.89 ± 0.93, with surgery 3.44 ± 1.13 (Table 12.).

Table 12. Comparison of Oxford, ASES, CM scores and muscle strength, humerus maximal sagittal flexion and VAS between BSN, BSI and AS subgroups. [62] Significant differences ($P<0.025$) are marked with *. Data of score, muscle strength, maximal sagittal flexion and VAS are given as mean±SD, N: Newton, dgr: degree, BSN: before surgery native subgroup, BSI: before surgery injection subgroup, AS: after surgery subgroup, SD: standard deviation, n.s.: not significant

	BSN	BSI	AS	*P* value
OXFORD score	27.7±10.2		43.5±3.5	**≤.0001***
ASES score	46.7±19.3		86.5±10.1	**≤.0001***
CM score	48.2±17.3		77.2±7.5	**≤.0001***
Jobe test (N)	32.0±18.2	32.9±19.1	47.6±20.0	BSN - BSI, .0742 BSN - AS, .0547
bear-hug test (N)	64.9±16.9	67.19±16.9	96.5±36.0	BSN - BSI, **.0136*** BSN - AS, **.0042***
external rotation force (N)	34.2±11.1	36.0±9.3	50.2±17.8	BSN - BSI, .0938 BSN - AS, .0547
humerus maximal sagittal flexion (dgr)	114.7°±33.5°	132.4°±21.6°	144.4°±18.6°	BSN - BSI, **.0163*** BSN - AS, **.0144***
VAS score	5.5±1.2	2.7±0.7	2.1±0.8	BSN - BSI, **≤.0001*** BSN - AS, **≤.0001***

5. Discussion

One of the aims of our research was to obtain valid upper limb measurements that are consistent with those found in the international literature.

Another aim of the study was to answer the question: in the case of moderate full-thickness supraspinatus tears is SD triggering the pain or is pain triggering SD? In other words, how does the elimination or reduction of pain influence the presence of SD? Furthermore, we were also curious if 6 months of routine rehabilitation treatment after surgery is sufficient to gain back the healthy scapular movement pattern.

Our aim was also to compare scapular dyskinesis with larger tears and to identify possible specific scapular rotational abnormalities.

5.1. Our results compared with the international literature in HG group – BSN subgroup comparison (Objective I.)

The lab was previously used for gait analysis, so converting the lab to upper limb analysis was a major challenge. The first 6 months of the research were spent practically on getting valid and reproducible measurements and on getting the VICON and ULEMA systems to work properly together. As a result, we have finally managed to produce results that are in line with internationally accepted values of scapula rotation. [61, 63] Furthermore, in HG group – BSN subgroup comparison we have been able to confirm the presence of increased protraction in moderate RC tears, which has been identified in previous biomechanical studies. [85, 92]

Our results showed significantly reduced forces in BSN subgroup measuring Jobe's test and body-next external rotation forces however, no significant difference was found between the two groups when performing the bear-hug test which are in accordance with studies by Miller [93], where a supraspinatus tendon rupture was also found with a decrease in strength during abduction and external rotation.

5.2. Effect of subacromial Lidocaine infiltration on scapular dyskinesis and shoulder joint function, BSN – BSI subgroups comparison (Objective II.)

5.2.1. Changes in scapular dyskinesis in response to Lidocaine infiltration

In our study, we observed a significant reduction in scapular protraction following subacromial injection of Lidocaine in the BSI subgroup. A significant reduction in pain on the VAS scale was also observed after injection [62], proving that the changes in the motion analyzis measurements were only affected by the pain, not torn muscle. In the BSI group we found that scapular protraction practically reached the protraction movement of the control group.

5.2.2. The effect of pain on scapular dyskinesis

Ettinger studied the effects of subacromial injections in patients with impingement syndrome. He analysed the rotational movements of the scapula during scapular plane arm elevation. He detected increased anterior tilting above 90° and identified increased scapular upward rotation between 60° and 90°. [94] But he could not confirm the elimination of dyskinesis. In contrast to Ettinger's results, we believe that there is a visible improvement in scapular dyskinesis as a result of the pain reduction. Indeed, a significant improvement in protraction was observed in our study. Scibek also analysed the effect of subacromial injection. [15] Our achievements are in line with his results, which show that with a decrease in pain, the degree of scapular dyskinesis also decreases. Our results also demonstrate that the decrease in pain as a consequence of the injection results in a decrease in scapular protraction. These results suggest that abnormal scapular movements are not primarily due to an altered biomechanical background as a result of RC rupture, but rather to pain.

5.2.3. Shoulder function in response to Lidocaine infiltration

Scibek's study also demonstrated that, in addition to reduced pain, the motion in the glenohumeral joint also improved [15], which is also consistent with our studies showing a significant increase in sagittal flexion of the humerus following subacromial infiltration. We also observed a significant increase in RC strengths in bear-hug test. [62]

5.3. Effect of arthroscopic RC reconstruction on scapular dyskinesis and shoulder joint function, BSN – AS subgroups comparison (Objective III.)

5.3.1. Changes in scapular dyskinesis after surgery

We observed a reduction in scapular protraction after surgery in the AS subgroup. Although this did not reach a significant level, it was close to the protraction movement pattern of the HG. However, no significant changes in anterior/posterior tilting and upward/downward rotation movements could be demonstrated. The results of our study are consistent with Kolk's findings. [92] His study also found increased protraction in patients with RC rupture, which significantly decreased one year after surgery. Six months after surgery, we also showed a decrease in protraction and a convergence to the values of the control group, but this did not reach a significant level. This may be due to the difference in timing of the controls, 6 months vs 1 year.

5.3.2. Shoulder function after surgery

At 6 months after RC reconstruction, the AS subgroup showed significant improvement in humerus sagittal flexion, all quality of life and functional scores, and significant improvement in the RC strength in bear-hug test. The improvements observed here are also in line with literature data reporting increased range of motion, improved muscle strength and decreased pain after RC reconstruction. [95, 96] The results also showed an increase compared to the BSI group. The improved results compared to the BSI group may be due to reduced or eliminated pain because of the intact rotator cuff and additional strength from the intact RC muscle strength. [62]

5.3.3. Effect of six months post-operative rehabilitation on scapular dyskinesis

Our study covered the outcome of postoperative rehabilitation of SD. There are many postoperative rehabilitation protocols, which may differ in their fixation method and duration, initiation of passive and active movements, accelerated or conservative. [97] However, comparative studies have demonstrated that there is no significant difference between patients' ROM and satisfaction at 6, 12 and 24 months. [98, 99] As a result, we performed repeated measures 6 months after surgery.

In our study, we observed a postoperative change mainly in scapular protraction, which tended towards the control group, but the change did not reach a significant level (Figure 21.). Kolk examined patients who underwent arthroscopic reconstruction for a moderate RC tear one year after surgery. Significant improvement was demonstrated in the protraction. [92] Song examined scapular rotations for moderate to large tears 1 year after surgery. He observed improvement in scapular dyskinesis in 52.1% of patients. He found the most significant improvement in posterior tilting in 75% of patients. [100] In the present study, we could not demonstrate a significant change in posterior tilting after surgery, changes were mainly detected in protraction, which may be due to differences in the size of RC tears. In our opinion, these results demonstrate that 6 months of rehabilitation treatment is not sufficient to eliminate SD.

5.4. Most typical scapula rotation changes observed in literature for RC ruptures of different sizes (Objective IV.)

Reviewing the literature, we find that large or massive tears have significantly increased upward rotation of the scapula compared to people without a tear. [101-103] This increased upward rotation of the scapula may persist even after surgery. In the study by Song, although there was an improvement in the degree of scapular dyskinesis 1 year after surgery, but this affected mainly posterior tilting and not upward rotation. [100] Comparing this with our own results, we could not demonstrate a significant increased upward rotation in either the BSN or AS group for moderate RC tears. Ueda also examined scapular rotations for small and massive RC tears 5 months after surgery. He still demonstrated significantly increased upward rotation in the group with massive tears at 5 months after surgery compared to the control group. [104] However, in our own study we demonstrated a decrease in protraction.

So, when we compare the literature with our own results, we mostly observe that for medium sized, full thickness RC ruptures, increased scapular protraction is more prevalent, whereas for large and massive ruptures, increased upward rotation is more dominant. This is probably because large tears affect the movement pattern of the scapula not only through pain but also through altered muscle function.

5.5. Limitations

Our study has some limitations. First, the number of patients is relatively small, which may bias our results and underpower the statistical analysis. However, motion analysis studies usually investigate small study groups due to the nature of such intensive studies. [104, 105] Despite the small number of items, the P-values are quite low for the protrusion values, where significant differences could be detected. Thus, with an increase in the number of patients, no change in the reporting of the main results is expected, possibly a quantitative change, but no qualitative one. Second, in the healthy control group, only RC ultrasonography was performed.

At the same time several factors support the strength of our study. First, we compared our measurements with a healthy group with demographic characteristics similar to the study group. Second, members of the study group had homogeneous tear sizes, allowing us to examine similar conditions. Third, the effects of injection and surgery were examined in the same group. Fourth, we measured scapular rotation during both the raising and lowering phases of the arm, bringing the measurements closer to clinical conditions where we often find that SD also occurs during the lowering phase. [6]

6. Conclusions

The effect of RC tear on scapular rotation and shoulder joint function was investigated. In the present study, we analysed RC tears of moderate size (1-3 cm) with full thickness.

The study compared the results of subacromial Lidocaine injection and arthroscopic single row RC reconstruction with those of the baseline and control groups.

6.1. Upper limb 3 D motion analyis (Objective I.)

I./1. We are able to perform upper limb 3D motion analysis. Our results are consistent with those found in the international literature.

6.2. Effect of subacromial Lidocaine injection (Objective II.)

II./1. Subacromial Lidocaine infiltration significantly reduced shoulder pain in the BSI subgroup after 10 minutes. Subsequent biomechanical measurements showed a significant reduction in scapular protraction towards HG protraction.

II./2. Pain has a causal role in the development of SD in RC tears of moderate full-thickness.

II./3. The BSI group showed a significant increase in the sagittal flexion of the humerus following a decrease in pain. In other words, for tears of this size, the RC can work in conjunction with the periscapular muscles to maintain proper shoulder function. Significant improvement was also demonstrated in the RC strength tests. Thus, for moderate RC tears in a painless condition, the RC has adequate muscle strength.

6.3. Effect of arthroscopic RC reconstruction (Objective III.)

III./1. Six months after reconstruction, pain was significantly reduced in the AS group. This improvement was greater than the reduction in pain provided by the injection. The biomechanical scapular motion analyses performed at this time demonstrated an increased reduction in protraction towards the HG protraction values, but did not reach the significant level.

III./2. In the AS group, a significant improvement in the sagittal flexion of the humerus was demonstrated, which exceeded the improvement allowed by the injection. After surgery, RC strength tests also showed a significant improvement, which also exceeded the improvement of the injection in the BSI group.

III./3. Six months of rehabilitation treatment is not sufficient to fully correct scapular dyskinesis after RC reconstruction for moderate tears.

6.4. Rehabilitation, main directions of SD (Objective IV.)

IV./1. The size of the tear can determine the direction of the SD. Medium-sized tears are dominated by increased protraction, large and massive tears by increased upward rotation.

6.5. Clinical relevance

1. In some patient groups or above a certain age, it is possible to treat moderate RC tears non-surgically, if pain can be reduced in the SA space, for example by steroid infiltration. As a significant improvements in SD, ROM and muscle strength can occur in the BSI subgroup.

2. After six months of surgical treatment, adequate muscle strength and ROM gains can be achieved in as little as 6 months compared to the healthy control group, but SD treatment takes longer, about 1 year based on literature data.

3. Based on our study and the literature review, the main direction of SD for RC ruptures of different sizes can be determined. For medium sized tears this is mainly increased protraction on the sacapula, whereas for large and massive tears it is increased upward rotation.

4. By knowing the main SD directions related to the size of RC tears, both conservative and postoperative rehabilitation treatments can be better targeted.

7. Summary

Our research suggests that pain plays a primary role in the development of SD in moderate RC ruptures. The main SD direction for moderate RC tears is increased scapular protraction. Based on our own data, SD is primarily a pain avoidance maneuver for moderate-sized tears. It seems that in moderate tears, RC is still compensated by the intactness of the horizontal axial force couples and is able to fulfill its function.

In contrast, in large and massive tears, the RC is not able to perform its necessary role in arm elevation and SD is a movement compensating process in which the scapula helps to elevate the arm through increased upward rotation. In other words, the classic 2:1 SHR is disrupted and the scapulothoracic joint has an increased role in arm lift.

This "reserve" of RC can be used in clinical practice also in older or polymorbid patients, as in painless cases with moderate RC ruptures, significant improvements in both range of motion and muscle strength can be achieved by injection analgesia. However, in younger, healthy people, surgical treatment is still recommended to regain full function and prevent further progressive RC ruptures.

An important finding is that 6 months of rehabilitation treatment after surgery does not eliminate SD. The literature suggests that a minimum of 1 year is required to resolve SD in such cases.

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9. Bibliography of the candidate's publications

I. Publications related to the subject of the thesis:

Nyőgér Z, Molnár CA, Szakály N, Várnagy A, Terebessy T, Gunther T, Skaliczki G. Scapula dyskinesis in medium-sized full-thickness rotator cuff tear after subacromial Lidocaine infiltration and rotator cuff reconstruction. J Exp Orthop. 2025;12(1):e70154. doi: 10.1002/jeo2.70154. PMID: 39917253; PMCID: PMC11799842.

Scopus - Orthopedics and Sports Medicine SJR indikátor: Q1

IF: 2,0

Nyőgér Z, Szakály N, Molnár CA, Várnagy A, Terebessy T, Gunther T, Skaliczki G. Scapuladyskinesis közepes méretű, teljes vastagságú supraspinatusizom-szakadások esetén [Scapula dyskinesis in medium size full-thickness supraspinatus muscle tears]. Orv Hetil. 2023;164(31):1213-21. doi: 10.1556/650.2023.32820. PMID: 37543973.

Scopus - Medicine (miscellaneous) SJR indikátor: Q4

IF: 0,8

II. Publications not related to the subject of the thesis:

Skaliczki G, Kovács K, Antal I, Sallai I, Kovács B, **Nyőgér Z**, Géresi Á, Kiss B, Várnagy A. Arthroscopic capsular release is more effective in pain relief than conservative treatment in patients with frozen shoulder. BMC Musculoskelet Disord. 2024;25(1):145. doi: 10.1186/s12891-024-07275-7. PMID: 38365741; PMCID: PMC10870563.

Scopus - Orthopedics and Sports Medicine SJR indikátor: Q2

Scopus - Rheumatology SJR indikátor: Q2

IF: 2,2

Gunther T, Farkashazi M, Mihalik G, **Nyoger Z**, Kovacs T. Functional outcome after lower limb periprosthetic fractures. Injury, 2021;52(Suppl 1):S44-S47. doi: 10.1016/j.injury.2020.06.017. Epub 2020 Jun 15. PMID: 32571546.

Scopus - Emergency Medicine SJR indikátor: Q1

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Scopus - Orthopedics and Sports Medicine SJR indikátor: Q2

IF: 2,687

Lénárth R, **Nyőgér Z**, Balogh P, Tömböl F, Gunther T. Hosszú szárú reverz vállízületi protézis alkalmazása a komplex, diaphysealis érintettséggel járó, darabos proximalis humerus törések kezelésében [Use of Long Stem Reverse Shoulder Arthroplasty in the Treatment of Comminuted Proximal Humerus Fractures with Complex, Diaphyseal Involvement.] Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet, 2022;65(1-4):19-29. doi: 10.21755/MTO.2022.065.0104.002.

Nyőgér Z, Gunther T, Balogh, P. Fiatal felnőttkori, töréssel és nagy dislocatióval szövődött elülső-radialis könyökficam ellátása, eredménye. [Treatment and result of juvenile anterior elbow dislocation with fracture.] Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet, 2020;63(1-4):41-47. doi: 10.21755/MTO.2020.063.0104.005.

A Központi Könyvtár igazolása:

I. **Az értekezés témájában megjelent eredeti közlemények** összesített impaktfaktor értéke: **2,8**

II. Egyéb – nem az értekezés témájában megjelent – eredeti közlemények összesített impaktfaktor értéke: **4,887**

I.+II. A könyvtári adatlapon feltüntetett közlemények összesített impaktfaktor értéke: **7,687**

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