Management of irreparable subscapularis tears: Current concepts

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ABSTRACT
Primary repair of acute subscapularis (SSC) tears provides excellent results, but tendon retraction, muscle atrophy, fatty infiltration, and humeral head migration may render a more chronic tear irreparable. These irreparable SSC tears present a diagnostic and treatment challenge for orthopaedic surgeons. Careful physical examination and imaging evaluation can help to distinguish those with reparable versus irreparable tears, but they are still not very reliable due to the methodological limitations of current evidence. Therefore, future research using 3D and quantitative measurement techniques is necessary to better predict the irreparability of the SSC.

When conservative treatment of an irreparable SSC tear fails, reversed shoulder arthroplasty has been established as the preferred treatment option for older, low-demand patients with arthropathy, providing reliable improvements in pain and function. In younger patients without significant arthropathy, musculotendinous transfers are the treatment of choice. The pectoralis major transfer is historically the most frequently performed procedure and provides improved range of motion and pain relief, but fails to adequately restore strength and shoulder function. The latissimus dorsi transfer has gained increased interest due to its biomechanical superiority, and early clinical studies suggest improved outcomes as well. More recently, anterior capsular reconstruction has been proposed as an alternative to musculotendinous transfers, but clinical data are completely lacking. Future high-quality randomised controlled trials are necessary to reliably compare the different musculotendinous transfers and anterior capsular reconstruction.

Current concepts
- Subscapularis tendon tears may become irreparable due to tendon retraction, muscle fatty infiltration and atrophy, and humeral head migration.
- In young, active patients without arthropathy, musculotendinous transfers are the preferred treatment option. The pectoralis major transfer is historically the most frequently performed procedure, but the latissimus dorsi transfer is gaining increased interest due to its biomechanical superiority.
- Anterior capsular reconstruction has been recently proposed as an alternative to musculotendinous transfers, but clinical data are lacking.
- Reversed shoulder arthroplasty is the preferred treatment option for older, low-demand patients with arthropathy.

Future perspectives
- Quantitative and 3D assessments of humeral head migration, tendon retraction, and muscle degeneration are necessary to better predict SSC reparability pre-operatively.
- High-quality randomised controlled trials are necessary to reliably compare the clinical results of the different musculotendinous transfers and anterior capsular reconstruction.

Introduction
Rotator cuff (RC) pathology is the most common source of shoulder disability. Tears of the subscapularis (SSC) have a reported incidence of 35% of all RC lesions [1,2]. The SSC muscle is the most powerful rotator
cuff muscle and predominantly functions as an internal rotator in isolation [3]. Furthermore, it has an important role in the dynamic stability of the glenohumeral joint, contributing to the coronal and transverse force couple [4–6]. Thus, SSC tears can cause an unbalanced force couple in the shoulder joint, leading to shoulder pain and decreased shoulder function [7].

It is generally accepted that large, acute, traumatic SSC tendon tears should be treated with surgical repair relatively urgently [8–10], which provides satisfactory outcomes [8]. When the diagnosis of an acute rupture is delayed, or in the case of an atraumatic, degenerative tear, [27].

Assessment of reparability

A thorough pre-operative assessment with clinical history, physical examination, and imaging studies is critical to identifying tear patterns that are (ir)reparable and to guide further treatment.

First of all, it is important to clearly define the term ‘irreparable tear’. In the strict sense of the term, an irreparable tear means that the tendon edge cannot be physically approximated and held securely to its anatomic footprint (= truly irreparable) [14,15]. But tears that have an unacceptable high likelihood of failure after repair are often considered irreparable as well [15–18]. Therefore, the term functionally irreparable RC tears was recently proposed, meaning those tears that may reach the footprint but will not heal [14]. Thus, irreparable tears can comprise both functionally and truly irreparable tears.

Clinical history and physical examination

Besides assessing pain and functional limitation, symptom duration is of specific interest, as it has been shown that the retear rate almost doubles when the time to surgery is more than 18 months and even rises drastically to 50% if it exceeds 30 months [11,19]. Furthermore, smoking, dyslipidemia, obesity, and diabetes have all been identified as possible risk factors for impaired healing or increased failure rate [19, 20], but evidence is contradictory on which of these factors are actual independent predictors [15,21–23]. Therefore, they are only considered relative contraindications.

During physical examination, the SSC is evaluated using a number of specific tests, such as the belly-press test [7], lift-off test [24], bear-hug test [25], and the IR lag sign [26]. A positive lift-off test is associated with a higher grade of FI, implying a greater risk of SSC irreparability [27].

Imaging

Standard radiographs and a magnetic resonance imaging (MRI) or computed tomography (CT) scan should be performed (Fig. 1). According to the classification of SSC tears by Lafosse, a SSC tear is deemed irreparable in the case of a complete tear with retraction to the glenoid rim, combined with a FI Goutallier stage 3 or 4 and/or anterior eccentricity of the humeral head [13].

Complete SSC tears are associated with major retraction in approximately two thirds of cases [10]. Meshram et al. found that retraction was a significant risk factor for retear, with a retraction of 19 mm having a sensitivity of 50% and a specificity of 80% [12]. Others found that major retractions lead to significantly more retears compared to minor retractions (20% vs 8%), and that the retear rate even rises to 50% in the case of Patte grade 3 retraction [10,28].

Furthermore, RC tears can lead to FI and atrophy of the RC muscle [29,30]. FI significantly correlates with non-healing after SSC tendon repair [10–12]. Retear rates are below 10% for Goutallier stages 0 and 1, but increase to 28% for stage 2 and even to 57% for stage 3 [11,31].

Muscle atrophy has been found to be an independent risk factor for non-healing after supraspinatus repairs [15]. Similar to the supraspinatus, SSC muscle atrophy can be assessed by failure of the SSC muscle outline to cross the tangent line from the edge of the coracoid to the inferior scapular tip. However, the association with non-healing has not yet been investigated for SSC tears [15].

Anterior HHM can be assessed on X-rays, CT, or MRI. Although it is generally accepted that fixed anterior HHM indicates irreparability of the SSC, the amount of HHM that can be accepted remains unclear [13].

In conclusion, fixed anterior HHM, advanced FI (grade 3 or 4 following Goutallier), and tendon retraction (grade 3 following Patte) are associated with irreparability of the SSC. Unfortunately, the assessment of FI, atrophy, and HHM suffers from methodological limitations. For example, assessment of FI with the Goutallier classification is limited due to its poor inter-observer and intra-observer reliability and its qualitative measurement [32,33]. In contrast, three-dimensional (3D) quantitative analysis of FI with Hounsfield unit-based measurements combined with 3D volumetric assessment of muscle atrophy has shown excellent

Fig. 1. Computer tomography (CT) scan images of a patient with an irreparable subscapularis tear. A: axial images illustrating the full-thickness tear with grade 3 retraction (arrowhead = tendon edge; arrow = footprint). B: sagittal image illustrating severe atrophy and fatty infiltration grade 4 (star = fatty tissue in the subscapularis fossa).
reliability [32,34]. Similarly, HHM should be assessed in 3D [15,35,36], both in a static and dynamic manner [37], instead of the current 2D static assessment. Therefore, further research is needed to better quantify the mentioned parameters in conjunction with a more detailed analysis of the possible correlation with irreparability.

Treatment

The treatment of irreparable SSC tendon tears depends on patient symptoms, patient demands, and the presence of arthropathy. If the SSC tear is deemed irreparable, a period of non-operative treatment can be tried, consisting of pain medication, nonsteroidal anti-inflammatory medication, corticosteroid injections, and physical therapy [8]. This has been reported to be effective in 70% to 75% of patients [38,39].

When conservative management fails, reversed shoulder arthroplasty (RSA) is generally the preferred treatment for older, low-demand patients. For younger, high-demand patients without arthropathy, joint-preserving options are preferred, consisting mostly of musculotendinous transfers. Contraindications for these transfers include an irreparable posterosuperior RC tear, as this will lead to a persistent disruption of the transverse force couple [18,40], and fixed anterior or proximal HHM [16-19,41]. The presence of arthropathy is another contraindication, although no clear cut-off has been reported yet [19,41].

Musculotendinous transfer

Musculotendinous transfers were first implemented for the treatment of functional loss due to nerve palsies [42]. In order to maximise the functional outcome of musculotendinous transfers, a number of basic principles have been proposed: 1) adequate strength and excursion of the donor tendon; 2) transfer of one donor tendon for each function to be replaced; 3) straight and comparable line of pull in comparison with the tendon to be replaced; 4) expendable donor, and 5) synergistic muscle [43].

Pectoralis major transfer

The pectoralis major (PMa) transfer is historically the most frequently performed procedure for irreparable SSC tears. It was first described by Wirth et al. in 1997 for the treatment of patients with irreparable SSC tears after failed instability surgery [44]. The line of pull of the PMa is comparable with the SSC in the coronal plane. However, the SSC originates from the subscapularis fossa, posterior from the chest wall, whereas the PMa originates anterior from the chest wall, making their lines of pull nearly perpendicular in the axial plane (Fig. 2). In an attempt to produce a more SSC-like vector, in line with the basic principles of musculotendinous transfers, the classic PMa transfer technique was later modified by routing the PMa deep to the conjoint tendon (subcoracoid transfer) [45,46] or by passing the sternal head of the PMa beneath the clavicular head [47]. However, these modifications create an angle in the line of pull of the transferred muscle, violating one of the basic principles of musculotendinous transfers. Furthermore, the subcoracoid transfer has been associated with a risk of conflict with the musculocutaneous nerve, especially in muscular patients [17,45].

Nine studies including a total of 184 shoulders [45,47–52] have been published regarding the clinical outcome of PMa transfer. Generally, they report a significant improvement in pain, shoulder function, and strength after PMa transfer. In 2021, these studies were included in a systematic review [16], which reported postoperatively an average visual analogue scale (VAS) pain score of 4, a constant score of 63, an active forward flexion of 130°, and an active IR approximately to the level of the waist. More than half of the patients had incomplete recovery of strength with a positive belly-press of 65% and a positive lift-off of 45% [16]. The transfer failed in 13% of cases, defined as a rerupture or pseudoparalysis of the shoulder. There was a complication rate of 15% including haematoma (3×), recurrent anterior instability (1×), deep venous thrombosis of the axillary vein (1×), seroma (3×), superficial infection (2×), transient musculocutaneous nerve neurapraxia (1×), and permanent axillary nerve palsy (1×) [16].

Pectoralis minor transfer

PMi transfer was first described by Wirth et al. in 1997 as well, but they preferred the PMa transfer because of the limited length and excursion possibility of the PMi [44]. Due to the mentioned shortcomings in clinical outcome and the risk of failure and complications with PMa transfer, PMi transfer was re-introduced for anterosuperior RC tears involving the supraspinatus and upper two-thirds of the SSC, arguing that PMi transfer is safer and less invasive with a better line of pull, although still originating from the anterior chest wall [53–55]. A disadvantage is the limited length and excursion of the PMi, possibly overstretching the muscle for optimal fibre contraction after transfer [53].

Only one clinical study is currently available, reporting the outcome of 27 patients after PMi transfer. They reported a good outcome with reliable pain relief and improvement of range of motion and functional scores, but only limited improvement in strength, with twothirds of pa-
tients having a positive lift-off test after PMi transfer [53]. One patient had a fracture of the coracoid, which healed conservatively. There were no other complications.

**Latissimus dorsi transfer**

In order to address the shortcomings associated with PMa and PMi transfer, the LD was proposed as a more suitable musculotendinous donor because it originates posteriorly from the chest wall, better mimicking the line of pull of the SSC (Fig. 2) [56]. In a biomechanical analysis, Kontaxis et al. [57] found that the IR moment arm of the LD transfer remained quite similar to the intact SSC throughout the total range of IR, whereas the IR moment arm of both the PMa and PMi reduced significantly after 30° of IR, even causing an anterior translation instead of IR torque past 60° of IR.

Three studies including 85 shoulders, have been published on the clinical outcome of LD transfer [18,58,59]. The procedure resulted in improved pain scores, shoulder function, ROM, and strength. Luo et al. compared the LD and PMa transfers in a systematic review including the aforementioned studies. They found significantly greater improvements in the constant score, ROM (abduction, forward flexion, and external rotation), and strength after a LD transfer. There was no statistical difference in complication or failure rate. The LD transfer failed in 7% of cases, and the complication rate was 15%, consisting of haematoma (1 ×), deep infection (1 ×), superficial infection (2 ×), seroma (3 ×), and wound dehiscence (1 ×) [16].

Although the LD transfer seems to give the most promising results, no definitive conclusions can be drawn as the mentioned clinical outcome studies suffer from some important limitations, such as significant differences in pre-operative clinical function, different surgical techniques used (open vs arthroscopically LD transfer, subcoracoid vs supra-coracoid PMa transfer, type of fixation), and concomitant lesions (supraspinatus or infraspinatus tears). Furthermore, long-term clinical studies are still lacking.

It is important to bear in mind that these musculotendinous transfers remain salvage procedures and that, although there is significant improvement in pain and shoulder function, patients cannot expect a normal shoulder function. Patients should be counselled that there will probably be some residual pain and limitations in ROM and strength.

**Lower trapezius and teres major transfer**

Although the line of pull of the LD transfer is comparable to the SSC in the axial plane, some authors have argued that it is almost 45° more vertical in the coronal plane, which causes a combined IR and downward force when contracting. In the search for a musculotendinous transfer that has a more similar line of pull as the SSC both in the axial and coronal planes, a lower trapezius transfer and a teres major transfer have been proposed. Both transfers were found to be feasible in a cadaveric study with low a risk of nerve compression [60,61]. A rhomboid minor transfer was suggested as well, but was advised against because of the risk of tendon luxation when externally rotating [60]. However, to our knowledge, no clinical results have been reported for these transfers yet.

**Anterior capsule reconstruction**

In the case of an irreparable SSC tear, the underlying anterior glenohumeral ligaments and capsule tear as well. Therefore, SSC tears comprise a disruption of not only the dynamic stabilisers (e.g., the SSC muscle) but also the static stabilisers (e.g., capsule and ligaments). For this reason, and drawing from the recent interest in superior capsular reconstruction for irreparable supraspinatus tears, some authors have suggested an anterior capsular reconstruction (ACR) with an allograft or autograft of the Achilles tendon, iliotibial band, or hamstrings [62–64]. The proposed benefits are a more anatomical reconstruction and a lower risk of nerve injury. Biomechanical analysis showed that ACR was able to restore the antero-inferior translation to normal in 60° of external rotation when an antero-inferior force was applied to the humeral head, in contrast to LD and Pma transfer [40,65]. However, the antero-inferior force in these studies was applied by an external force at the humeral head, which is not physiological, and the results were only significant when this force exceeded 30 N, which was very high compared to the loads applied to the other muscles. But above all, it does not restore the dynamic function of the deficient SSC. Only 2 case reports have been published with regard to the clinical outcome of ACR in cases of irreparable SSC tears, and thus, clinical evidence is currently lacking [66,67].

**Reversed shoulder arthroplasty**

RSA as a treatment of irreparable RC tears without arthropathy leads to promising short-to-mid-term results with reliable pain relief and improvement of shoulder function to approximately 125° of elevation and IR to L2 [68]. However, some risk factors for poor outcomes have been identified such as age less than 60 and a good pre-operative function with active elevation above 90° [69,70]. RSA is especially a concern in young patients because of deltoid fatigue, implant longevity issues, and a high complication rate of 40% [19,70,71]. To our knowledge, there is no specific data available on RSA for irreparable SSC tears.

**Conclusion**

Patients with irreparable SSC tears present a diagnostic and treatment challenge for orthopaedic surgeons. Careful physical examination and imaging evaluation can help to distinguish between reparable and irreparable tears. Fixed anterior HHM, advanced FI (grade 3 or 4 following Goutallier), and tendon retraction (grade 3 following Patte) are associated with irreparability of the SSC, but methodological limitations in their assessment prevent highly reliable use in daily practice. Future research, using 3D and quantitative measurement techniques, is necessary to better predict the irreparability of the SSC.

When conservative treatment fails, musculotendinous transfers are the preferred treatment in young, active patients without significant arthropathy. The pectoralis major transfer is historically the most frequently performed procedure and provides improved outcome and pain relief, but fails to adequately restore strength and shoulder function. The latissimus dorsi transfer has recently gained increased interest due to its biomechanical superiority. It does seem to result in a better clinical outcome, but the available evidence is only of fair quality, and long-term follow-up studies are lacking. More recently, anterior capsular reconstruction has been proposed as an alternative to musculotendinous transfers, but there is only limited biomechanical evidence and a complete lack of clinical studies. Future high-quality randomised controlled trials are necessary to reliably compare the different musculotendinous transfers and ACR.

In older, low-demand patients with arthropathy, or in cases of contraindications for musculotendinous transfers, RSA is the treatment of choice, providing reliable improvements in pain and function. However, caution is advised for performing RSA in younger patients with minimal arthropathy and good pre-operative function, as they may not achieve their desired functional improvement and because of the high risk of complications and concerns regarding implant longevity.

**Declaration of competing interest**

The authors declare that there is no conflict of interest.

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