Upper Extremity Injuries in Different Age Groups - A Common Paediatric Bone Injury and a Common Adult Soft Tissue Injury on the Upper Extremity

PhD Thesis

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1. List of abbreviations

AAOS: American Academy of Orthopaedic Surgeons
ASES: American Shoulder and Elbow Surgeons
AP: Anteroposterior
ASC: Arthroscopy
BMI: Body Mass Index
CAL: Coracoacromial Ligament
CHL: Coracohumeral Ligament
CI: Confidence Interval
CRPP: Closed Reduction and Percutaneous Pinning
CRT: Capillary Refill Time
CT: Computed Tomography
ED: Emergency Department
FDR: False Discovery Rate
GRADE: Grading of Recommendations Assessment, Development, and Evaluation
IGHL: Inferior Glenohumeral Ligament
IS: Infraspinatus
Kg: Kilogram
K-wire: Kirschner-wire
LHBT: Long Head of the Biceps Tendon
MCID: Minimal Clinically Important Difference
MGHL: middle glenohumeral ligament
MRI: Magnetic Resonance Imaging
N: Newton
n.a.: Not Available
OR: Odds Ratio
PICOTS: Population, Intervention, Comparison, Timing, Study type
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RC: Rotator Cuff
RCT: Randomized Controlled Trial
RoB: Risk of Bias
SCHF: Supracondylar humerus fracture
SD: Standard Deviation
SGHL: superior glenohumeral ligament

SI: Strength Index
SLAP: Superior Labrum Anterior and Posterior
SS: Supraspinatus
SSc: Subscapularis
SST: Simple Shoulder Test
STROBE: STrengthening the Reporting of OBservational studies in Epidemiology
TD: Tenodesis
THL: Transverse Humeral Ligament
TM: Teres Minor
TT: Tenotomy
TSA: Trial Sequential Analysis
UCLA: University of California at Los Angeles
VAS: Visual Analog Scale
WMD: Weighted Mean Difference

2. Preface

This dissertation represents the results of the work of a PhD applicant who got involved in more than one project in his field of study. Since his interest lies in the subspeciality of shoulder and elbow surgery, he chose to explore the entire anatomical region in order to gain a complex view and thorough understanding of this topic.

3. Introduction

Upper extremity injuries refer to any form of damage or trauma that affects the structures from the shoulder to the fingers, including fractures, dislocations, soft tissue injuries and degenerative changes. The upper extremity is an anatomically and functionally complex system that facilitates fine-motor tasks, enables load bearing, and contributes substantially to overall quality of life.

A U.S. study found that 18.6% of injury-related hospital visits was necessary due to injuries to the upper extremity, making it the most frequently injured region [1]. The majority of these injuries affects the fingers, followed by the shoulder region, forearm, wrist, elbow, and upper arm [2].

Most incidents occur at home, with sports-related and school injuries also noted [2]. In paediatric populations, upper extremity injuries in the first decade of life are primarily caused by play-related accidents, while sports and traffic-related accidents dominate in the second decade, with falls being the most frequent injury mechanism [3]. The yearly trend in emergency department (ED) visits shows bimodal peaks during the summer and fall (June and October), with a low point in the winter (January) [4].

Overuse injuries and degenerative changes in the upper extremity pose a significant burden on both patients and society. The shoulder is particularly prone to overuse injuries due to its extensive range of motion. These injuries commonly occur in younger, active individuals, for example athletes, but pathologies like impingement affect older populations more often [5].

Effective management of these injuries through early diagnosis, appropriate medical interventions, and targeted rehabilitation programs are critical to restoring function and preventing long-term disability.

3.1. Anatomical and Functional Significance of the Shoulder and Elbow

3.1.1. Shoulder

The shoulder complex comprises several bones: the clavicle, scapula, and humerus. Key joints include the glenohumeral, acromioclavicular, and sternoclavicular joints, along with the scapulothoracic articulation, which is not a true joint but crucial for shoulder mechanics. The glenohumeral joint, a ball-and-socket type, offers the widest range of motion but is inherently unstable, relying heavily on soft tissue structures for stability [6, 7].

Ligaments enhancing shoulder stability include the superior (SGHL), middle (MGHL), and inferior (IGHL) glenohumeral ligaments. These ligaments support the joint by preventing excessive movement and stabilizing the biceps tendon, while the coracohumeral ligament (CHL) limits external rotation and the coracoacromial ligament (CAL) protects against superior dislocation of the humeral head. The acromioclavicular joint is stabilized by the acromioclavicular and coracoclavicular ligaments, which prevent excessive shifting of the clavicle relative to the scapula [6, 7].

The muscular anatomy of the shoulder is dominated by the rotator cuff, consisting of the subscapularis (SSc), supraspinatus (SS), infraspinatus (IS), and teres minor (TM) muscles and tendons. These muscles not only facilitate movement but also contribute to joint stability by maintaining the humeral head within the shallow glenoid cavity during motion. The deltoid, larger and more superficial, is primarily responsible for arm abduction. Other muscles like the pectoralis major, latissimus dorsi, and trapezius support various movements and stabilize the shoulder complex [6–8].

While the joint is primarily supported by the rotator cuff (RC) [8], numerous cadaver studies [9–13] indicate that the long head of the biceps tendon (LHBT) plays a crucial role as a stabilizer and depressor of the humeral head. However, the findings of in vivo studies remain controversial regarding the LHBT's function [14–16].

The CHL and SGHL join with fibers from the subscapularis tendon (SScT) and supraspinatus tendon (SST) to form the biceps pulley, stabilizing the LHBT as it enters the bicipital groove where it continues deep to the transverse humeral ligament (THL) (Figure 1.).

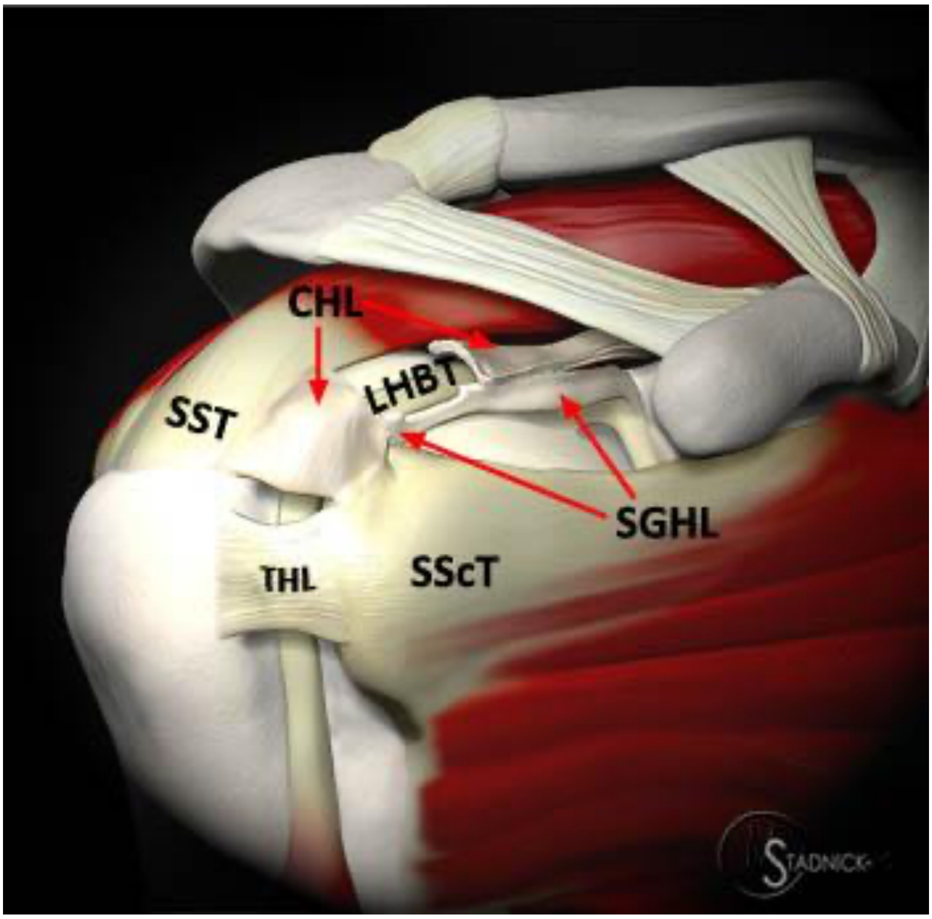

Figure 1. *Tendons and ligaments of the shoulder* [17].

Movements at the shoulder include abduction, adduction, flexion, extension, and internal and external rotation. These motions occur primarily at the glenohumeral joint but require coordinated activity across all shoulder components to achieve the complex movements necessary for daily functions and athletic activities [6, 7].

Due to the demands of strength, endurance, and flexibility placed on the shoulder in daily activities, it frequently becomes a site of musculoskeletal issues and pathology [6].

3.1.2. Elbow

The elbow anatomy includes the articulation of three bones: the humerus, radius, and ulna. This configuration forms the ulnohumeral, radiocapitellar, and proximal radioulnar joints, each contributing to the elbow's functions [18–20].

The ulnohumeral joint, mainly responsible for flexion and extension, is stabilized by the trochlear notch of the ulna articulating with the trochlea of the humerus. The radiocapitellar joint allows for movement of the radial head against the capitellum of the humerus, playing a role in flexion-extension and rotational movements of the forearm [18, 20].

Fat pads are located in the anterior coronoid and radial fossae, as well as the posterior coronoid fossa, and are all enclosed within the joint capsule [20]. Ligaments such as the medial (ulnar) and lateral (radial) collateral ligaments contribute to elbow stability. The medial collateral ligament is vital for resisting valgus forces. The lateral collateral ligament complex resists varus forces and supports rotational stability [18, 20] (Figure 2.).

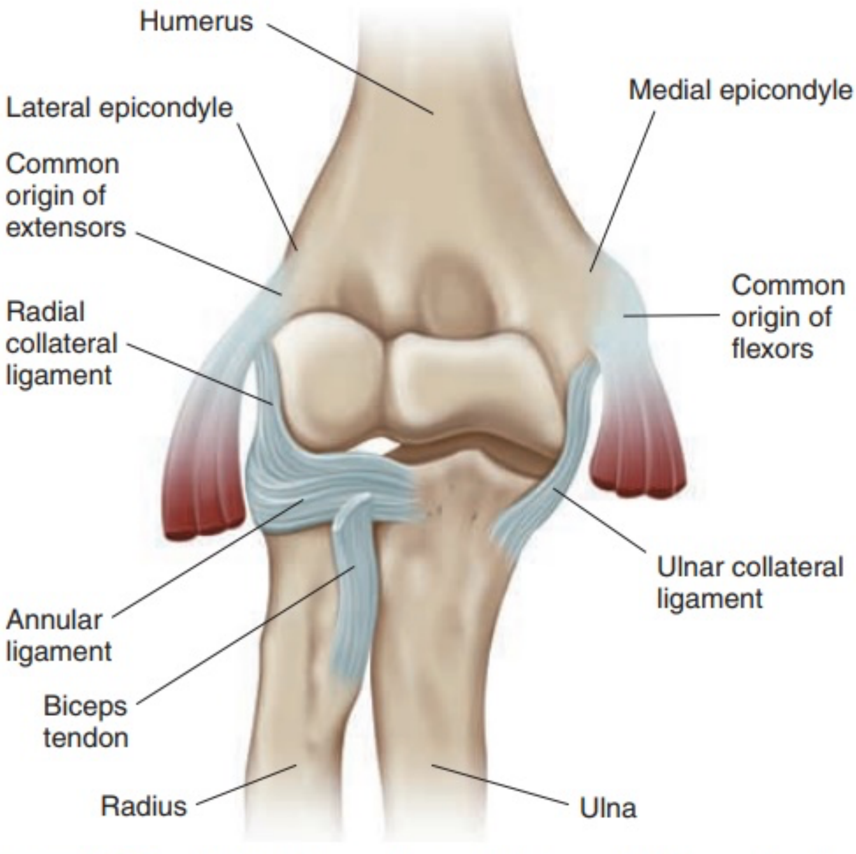

Figure 2. *Elbow joint, showing ligaments* [21].

The elbow's carrying angle, where the forearm deviates laterally from the body, varies between individuals and is more pronounced in females [19, 20].

The elbow features four primary muscle groups: the anterior bicep group, the posterior tricep group, the lateral extensor-supinator group, and the medial flexor-pronator group. Primary muscles responsible for flexing the elbow include the brachialis, biceps brachii, and brachioradialis. Elbow extension is primarily facilitated by the triceps, and the anconeus. Pronation is driven by the pronator teres and pronator quadratus. Meanwhile, supination is predominantly performed by the biceps, supported by the supinator muscle [18].

Four nerves—the median, radial, musculocutaneous, and ulnar— traverse the elbow's anatomy and often display anatomical variations [19]. The brachial artery features many branches in the arm, creating extensive collateral circulation around the elbow. This robust blood supply means that injuries to the brachial artery at the elbow does not always result in distal ischemia [20].

The elbow joint works in tandem with the shoulder to position the hand accurately in space. Given the shoulder's wide range of motion across all three axes, the demand for elbow mobility is reduced. Movements at the elbow include flexion-extension through the ulnohumeral joint and pronation-supination through the proximal radioulnar joint [18].

3.1.3. Impact of Shoulder and Elbow Injuries on Limb Function and Quality of Life

3.1.3.1. Shoulder Injuries

Shoulder pain is estimated to be the third most common musculoskeletal complaint in primary care, following low back pain and knee pain [22]. Disorders of the shoulder, such as fractures, dislocations, rotator cuff tears, and tendon pathologies like pathologies of LHBT can greatly impact a patient’s ability to work and perform daily activities, including driving, dressing, brushing their hair, and even eating [23], thus greatly reducing quality of life.

The prevalence of shoulder pain has been noted to affect 16% of the general population (range, from 0.67% to 55.2%) [24], with higher incidence noted in jobs involving repetitive overhead activities or in sports [25].

The pathology of the LHBT encompasses inflammation, partial or complete ruptures (including superior labrum anterior and posterior [SLAP] lesions), and instability [26]. These conditions can result in anterior shoulder pain or impaired function [27] and are frequently linked to other shoulder pathologies, such as rotator cuff tears [28–32].

In patients undergoing RC repair, the reported incidence of LHBT pathology varies widely across studies, ranging from 36.1% to 82% [30, 31].

3.1.3.2. Elbow Injuries

Elbow injuries can also be severely debilitating. They often result in persistent stiffness, decreased range of motion, and chronic pain, affecting daily activities such as lifting objects, using tools, or performing fine motor tasks.

Fractures, dislocations, and overuse injuries like tennis elbow are common and can lead to significant functional impairment if not properly managed [33, 34]. In a study by Herquelot et al. [35], 10.5% of the examined population reported experiencing elbow pain over a 12-month period, all of whom were active workers. The study also revealed that manual labour placing stress on the joint significantly increased the prevalence of elbow pain.

Supracondylar humerus fractures (SCHFs) remain a significant concern for the paediatric population due to their high prevalence and potential complications [36]. 95% of these injuries happen when a child falls and instinctively extends an arm to protect from the impact. [37]. During such incidents, the olecranon generates excessive extensional force on the distal humeral cortex, leading to a fracture. Children are particularly vulnerable during holidays, often while playing on playground equipment, especially trampolines [37].

Flexion-type SCHFs are less common, constituting to around 5% of cases. These injuries typically occur in the non-dominant arm of older children when they fall on a flexed limb [34].

The estimated incidence of SCHFs ranges from 3.3% to 17.9% [38, 39]. SCHF injuries are the most common fractures involving the elbow in paediatric patients [40]. The mean age of affected children typically ranges from 4.7 to 7.2 years [41, 42]. While many studies report a higher incidence in males [39, 41], some findings indicate a greater prevalence in females [43].

SCHFs can be classified by the degree of fragment displacement, most commonly using the Gartland classification system modified by Wilkins [44]. Type I fractures are non- or minimally displaced (<2 mm). Type II injuries are displaced (>2 mm) but retain an intact posterior cortex or hinge (IIA), with the possibility of additional malrotation (IIB). Types III and IV involve complete displacement, with a disrupted posterior hinge characterizing Type III, and multidirectional instability indicating Type IV [44] (Figure 3.). Type IV is typically an intraoperative diagnosis, however this injury should be considered when, despite a complete cortical disruption, the distal fragment remains vertically aligned on lateral radiographs [45].

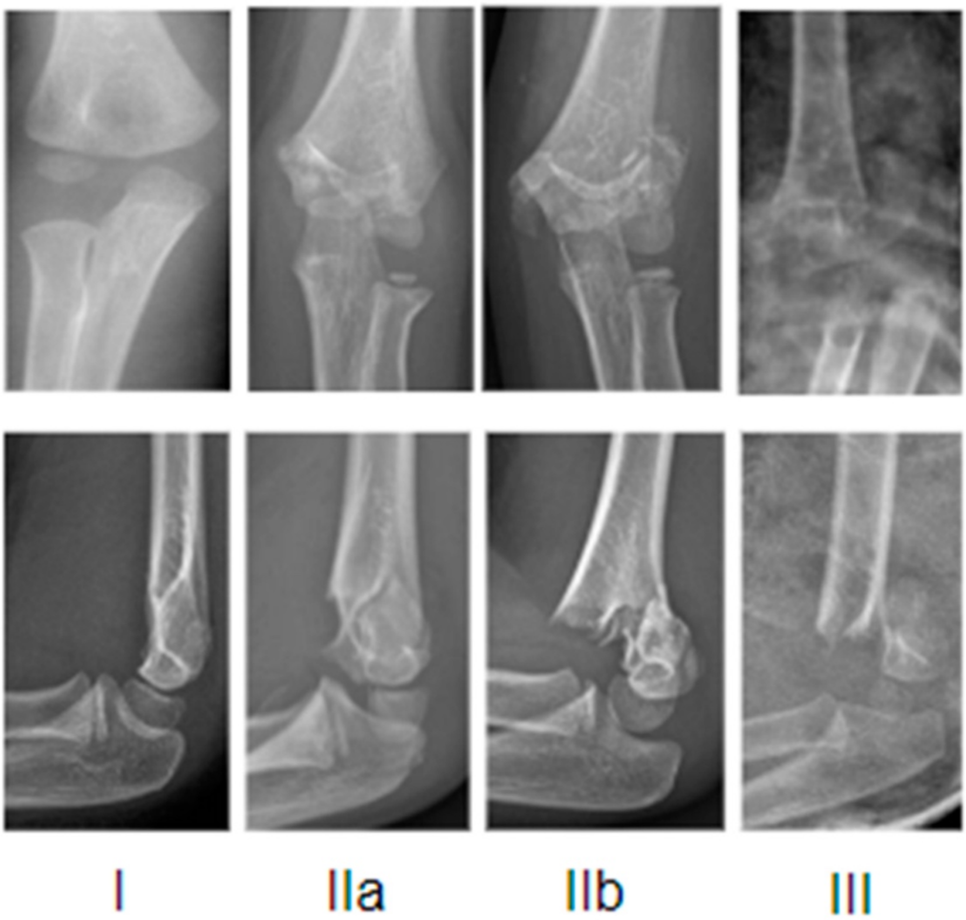

Figure 3. *Radiographs representing the Gartland classification [46].*

3.2. Diagnostic Methods and Tools for Shoulder and Elbow Injuries

3.2.1. Physical examination

3.2.1.1. Shoulder

Key components include inspection for deformity or swelling, palpation of the joint to identify areas of tenderness, and range of motion tests [23]. Specific tests like the Hawkins-Kennedy impingement test, the Neer impingement sign, or the O'Brien test can help diagnose specific pathologies like impingement syndromes or labral tears [6]. There are tests for examining rotator cuff pathologies, like the Jobe, or belly-press tests [6].

3.2.1.1.1. LHBT Assessment

Clinical evaluation of the LHBT involves specific tests like the Speed’s test and Yergason’s test, which help in identifying biceps tendon pathology [6]. Palpation of the bicipital groove can also reveal tenderness associated with LHBT disorders.

3.2.1.2. Elbow

Includes testing for range of motion, swelling, and tenderness. Specialized tests like the valgus stress test for medial collateral ligament instability, the Tinel sign for ulnar nerve irritation, or the chair test for lateral epicondylitis are routinely performed [47].

3.2.1.2.1. SCHF Assessment

During the physical examination, common fracture indicators—such as swelling, pain, bruising, or limb deformity—are typically observed [48] (Figure 4.).

Figure 4. *Swelling, bruising and limb deformity seen in SCHF.*

Because of the significant likelihood of neurological injury, it is imperative to thoroughly evaluate distal sensory and motor function. To examine the motor innervation of the hand, the "rock, paper, scissors, OK" gesture sequence is a useful method. The "rock" tests the function of the median nerve, "paper" examines the radial nerve, "scissors" assesses the ulnar nerve, and "OK" evaluates the anterior interosseous nerve [49]. Anterior interosseous nerve palsy is most commonly associated with extension-type traumas, whereas ulnar nerve paresis frequently occurs in flexion-type fractures; however, the median and radial nerves may also be involved [50].

Vascular injury is likewise common, usually affecting the brachial artery [51]. It may either be tented over or anchored at the fracture site [51]. In some instances, detaching it from the fracture site may resolve the issue, while in other cases, reconstruction may be required, frequently involving vein grafting [51]. Consequently, assessing radial and ulnar pulses, along with evaluating capillary refill time (CRT), colour, and temperature, and comparing it to the ipsilateral arm, is crucial.

3.2.2. Radiography (X-ray)

Radiography is the first-line imaging tool for assessing bone injuries in the shoulder and elbow regions [52–54]. It provides valuable information on fractures, joint alignment, and the presence of arthritic changes. For shoulder injuries, standard views include the anteroposterior, lateral, and scapular Y views, which help in evaluating dislocations and fractures of the proximal humerus and glenoid [55]. For the elbow, anteroposterior and lateral views are standard [56]; they are particularly effective in identifying fractures of the radial head, olecranon, and distal humerus.

3.2.2.1. LHBT Specifics

For the LHBT, standard shoulder X-rays are often inadequate to diagnose specific tendon pathologies but can show associated changes such as bony spurs on the superior glenoid or humeral head that may impinge on the tendon. Advanced techniques like the Fisk radiograph can be more informative [57].

3.2.2.2. SCHF Specifics

In paediatric SCHFs, anteroposterior (AP) and lateral radiographs are essential for classification according to the Gartland system, which is critical for choosing the best treatment option. Radiographs help in identifying the extent of the fracture displacement and integrity of the posterior cortex [56].

Because much of a child's elbow consists of nonossified cartilage at the typical ages for distal humerus fractures, interpreting paediatric elbow radiographs can be challenging. In children, growth centres appear in a predictable sequence based on age and sex. Understanding this timeline is essential for accurately evaluating paediatric elbow fractures on radiographs and making informed treatment decisions [48].

On a lateral radiograph, it's important to evaluate the classic figure-eight shape of the distal humerus and the anterior humeral line. Normally, a line traced along the anterior cortex of the humerus will intersect the middle third of the capitellum. However, with a supracondylar fracture, the capitellum typically shifts posterior to this line [58].

Without an obvious fracture line, subtle indicators such as a posterior fat pad or a prominent, triangular sail-shaped anterior fat pad suggest an intra-articular joint effusion accompanied by a fracture [58] (Figure 5.).

Figure 5. *Posterior fat pad sign as it appears on radiography.*

3.2.3. Magnetic Resonance Imaging (MRI)

MRI is a non-invasive diagnostic tool that provides detailed images of both osseous and soft tissues including bones, muscles, tendons, ligaments, and cartilage [59]. This makes it ideal for diagnosing rotator cuff tears, labral tears, and tendonitis in the shoulder, as well as ligament injuries and cartilage defects in the elbow. Magnetic resonance imaging is widely regarded as the gold standard for non-invasive shoulder assessment [60], however, performing an MRI on children may necessitate assistance from an anaesthesiologist team.

3.2.3.1. LHBT Specifics

MRI is a useful choice for assessing the LHBT as it offers detailed images of the tendon's integrity, its position within the bicipital groove, and any associated lesions such as SLAP tears (Figure 6.). A comprehensive assessment of the entire tendon, including its intra-articular portion, is most effectively achieved through MR imaging, often using MR arthrography [60].

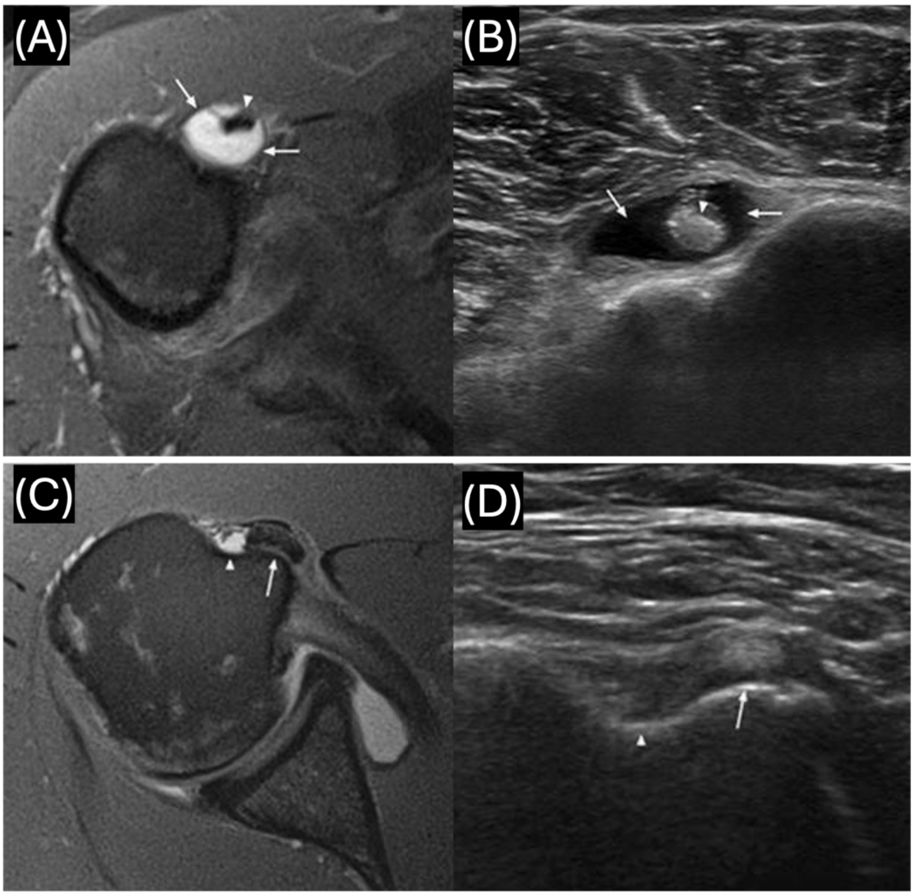

Figure 6. *LHBT Tenosynovitis: (A) Axial T2-weighted fat-suppressed MR and (B) transverse ultrasound image reveal fluid surrounding the LHBT (arrowhead) within the biceps tendon sheath (arrows). LHBT Subluxation: (C) Axial T2-weighted fat-suppressed MR and (D) transverse ultrasound image shows the biceps tendon (arrows) medially displaced, resting on the medial rim of the bicipital groove. The bicipital groove itself (arrowhead) is devoid of the tendon* [61].

3.2.3.2. SCHF Specifics

Although MRI can provide detailed views of soft tissue status around the elbow, it is not routinely performed in paediatric SCHFs, because it can be time-consuming, and often hard to carry-out in small children, especially in emergency situations.

3.2.4. Computed Tomography (CT) Scan

While MRI is superior for soft tissue evaluation, CT scans are usually more effective at providing detailed images of bone architecture. CT is often used when complex fractures are suspected in the shoulder and elbow, as it can clearly depict the extent of fracture displacement. For example, after shoulder dislocation CT imaging is frequently utilized to evaluate the extent of glenoid bone loss and to aid in fracture fixation planning [55].

3.2.4.1. LHBT Specifics

CT scans are generally not used for diagnosing LHBT issues directly but can be helpful in identifying associated injuries such as fractures or major dislocations that might affect the biceps tendon indirectly.

3.2.4.2. SCHF Specifics

CT scans could be valuable in complex elbow fractures where fine details about fracture alignment, comminution, or the presence of intra-articular fragments are useful for surgical planning, but in clinical practice it not routinely used to diagnose SCHFs. However, a CT scan can help measure rotational errors in cases of improperly healed fractures, such as cubitus varus [49], or a CT angiography might be performed in case of insufficient circulation before or after surgery (Figure 7.).

Figure 7. *Postoperative CT angiography after CRPP of an SCHF. It shows occlusion of the brachial artery near the fracture.*

3.2.5. Ultrasound

Ultrasound offers high spatial resolution for soft tissues—like tendons and muscles—yet its high attenuation coefficient results in limited visualization of bone and intra-articular structures, including the labrum and articular cartilage [60]. Ultrasound is particularly adept at detecting fluid both within and around a joint, such as effusions or bursitis. Another key benefit is its dynamic capability, which allows assessment of subacromial impingement, biceps tendon subluxation, and AC joint separation. Additionally, its real-time imaging facilitates ultrasound-guided procedures, like injections [60].

3.2.5.1. LHBT specifics

The most frequently observed findings are increased LHBT diameter and the presence of hypoechogenic areas, but pathological fluid is also often seen [62]. Dynamic ultrasound testing can be used in real-time to assess the movement of the LHBT within the bicipital groove during different arm positions and movements. This method helps in detecting subluxations or dislocations of the tendon during motion [60] (Figure 6.).

3.2.5.2. SCHF specifics

Injuries involving the skeletally immature elbow often pose significant diagnostic challenges, particularly when evaluating non-ossified epiphyses, where standard radiography offers limited insight. Ultrasound provides a diagnostic advantage over conventional radiographs due to its ability to visualize cartilage. The detection of a joint effusion or hemarthrosis strongly indicates a possible fracture [63] (Figure 8.).

Figure 8. *Posterior fat pad sign as it appears on ultrasound.*

3.3. Overview of Treatment Options for LHBT and SCHF Injuries

3.3.1. Conservative Management

3.3.1.1. LHBT Injuries

Nonoperative management is the first-line approach for both primary and secondary bicipital tendinopathy, typically involving rest and avoidance of aggravating activities, ice application, anti-inflammatory medications, and structured physical rehabilitation [64]. However, few studies focus exclusively on conservative management of isolated biceps lesions, as these injuries often co-occur with other pathologies [64]. Because patient presentations differ, conservative management of biceps pathology is highly individualized.

Physical therapy interventions in LHBT management highlight the use of ultrasound, extracorporeal shockwave therapy, electrotherapy, strengthening, joint mobilization, eccentric exercise, dry needling, and polarized light therapy [65].

Ultrasound guided steroid injections can also serve an important role in treating patients with LHBT disorders [66].

3.3.1.2. SCHF Injuries

According to the AAOS (American Academy of Orthopaedic Surgeons) guidelines, nonsurgical immobilization of the injured limb is advised for patients with nondisplaced paediatric supracondylar humeral fractures (e.g., Gartland type I), as well as those presenting with a posterior fat pad sign [67]. Based on two studies [68, 69], immobilizing Gartland type I fractures with an above-elbow back slab offers more effective pain relief and greater comfort for paediatric patients than collar-and-cuff immobilization [67]. Elevated straight-arm traction can be an effective treatment method in settings with limited resources [70]. The clinical experience of the surgeon and other factors, such as associated injuries, comorbidities, skeletal maturity, or obesity, also play a crucial role in determining treatment options [67].

Supracondylar humeral fractures are typically immobilized for one to four weeks [69]. The elbow is often flexed slightly beyond 90 degrees and the forearm in neutral rotation [71].

3.3.2. Surgical Interventions

3.3.2.1. LHBT Injuries

When conservative treatment for a disorder of the LHBT has been deemed unsuccessful, surgical intervention becomes necessary [72]. The two options are tenotomy and tenodesis. When choosing between these two interventions, several factors are taken into account, such as the patient's age, anticipated functional demands, cosmetic concerns, or the time required for surgery [72].

Biceps tenotomy is a simpler procedure that hypothetically involves a shorter duration of surgery and fewer postoperative restrictions, enabling a quicker return to full activity [73].

Biceps tenodesis is theoretically beneficial as it maintains the normal length-tension relationship of the tendon, which can enhance both the cosmetic appearance post-surgery and functional outcomes. Consequently, it is generally recommended for younger, active patients who have higher functional demands [73].

Surgical treatment of the tendon is often carried out during arthroscopy, typically in conjunction with other procedures such as rotator cuff repairs. Arthroscopic evaluation of the long head of the biceps tendon includes inspecting the tendon for signs of fraying, tearing, erythema, and vascular injection. The portion of the tendon within the bicipital groove is also examined by bringing it into the joint and visualizing it, which is facilitated by applying traction to the tendon using a probe [74]. Each method has multiple surgical approaches.

Tenotomy, the simpler procedure, involves detaching the tendon from the supraglenoid tubercle [72]. This can be done in many ways, for example with creating a funnel-shaped proximal stump [75], performing self-locking "T" tenotomy [76] or by detaching the LHBT along with a part of the superior labrum [77]. These techniques can help prevent complete biceps retraction and may lead to fewer occurrences of Popeye deformities following biceps release than in "regular tenotomy", while at the same time they can lead to lower levels of postoperative pain [76].

Tenodesis may be carried out either arthroscopically or through an open approach, with the tendon anchored to various anatomical locations in either soft tissue or bone. The site for tenodesis might be suprapectoral or subpectoral [78], and fixation techniques can include suturing to tendons, using interference screws, bone tunnels, keyholes, suture anchors, sutureless anchors [27, 74, 79, 80] (Figure 9.). According to a network meta-analysis [73], when compared directly, open subpectoral tenodesis yielded significantly better postoperative ASES (American Shoulder and Elbow Surgeons) and Constant scores, surpassing alternative techniques and fixation methods.

Most patients who undergo these procedures also receive an additional concomitant procedure, typically either rotator cuff repair or distal clavicle resection [82].

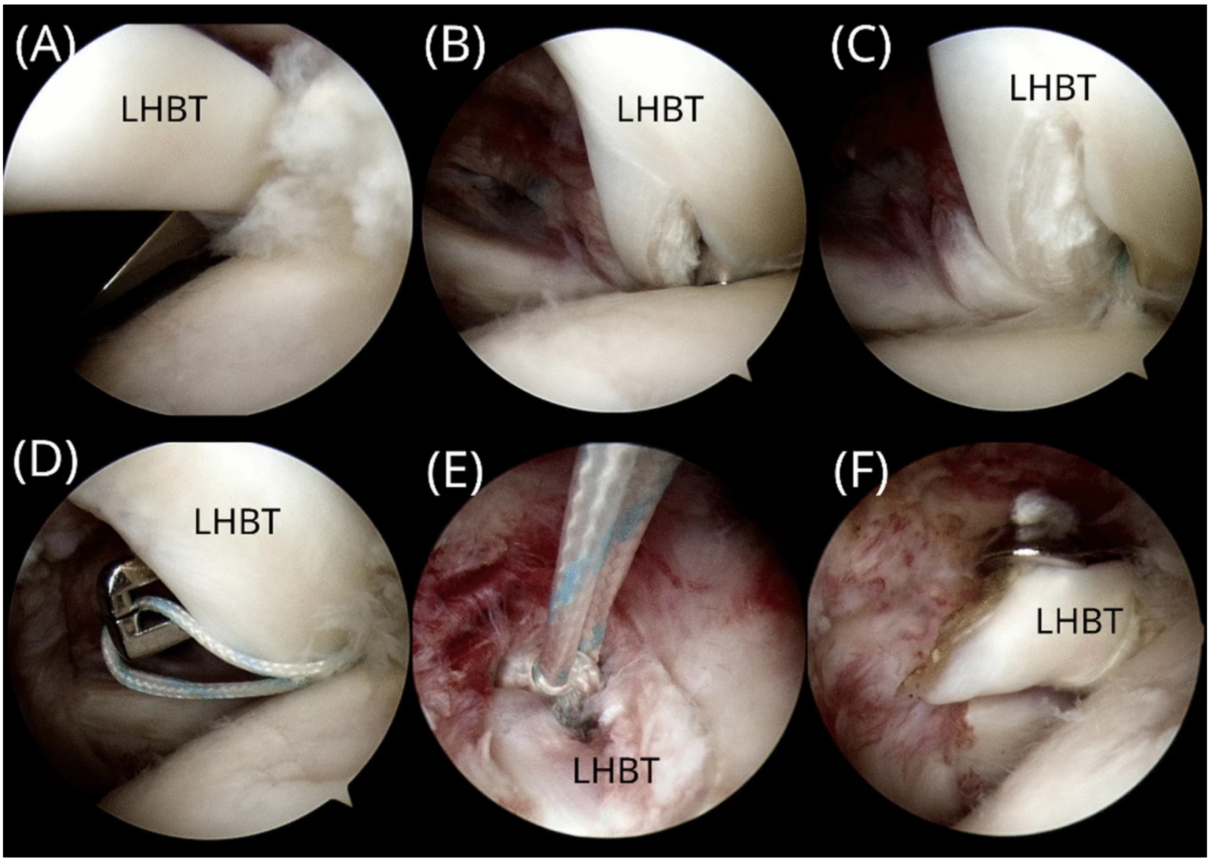

Figure 9. *Intraoperative images of the modified transtendinous looped biceps tenodesis (mTLBT) technique. (A) surgical blade is used to make an incision in the long head of biceps tendon (LHBT). (B): A drill guide and an obturator are placed through the LHBT. (C) After pre-drilling, a suture anchor is inserted through the tendon and into the pilot hole. (D) A limb of the suture is passed beneath the tendon for looping the LHBT. (E): The suture limbs are tied on the tendon. (F): Biceps tenotomy is performed, leaving at least 0.5 cm of the tendon stump [81].*

3.3.2.2. SCHF Injuries

The choice of conservative versus surgical management largely depends on fracture displacement and stability. According to AAOS recommendations [67], closed reduction with pin fixation is advised for children with displaced SCHFs (e.g., Gartland types II and III or displaced flexion fractures) [67], but we can find evidence, that suggests otherwise. For example, the study made by Ariyawatkul et al. [83], some Gartland type IIA fractures can be treated with closed reduction and casting, while in type IIB, internal fixation is recommended because of expected displacement.

If the injured limb is pulseless yet remains pink and well-perfused, it indicates effective collateral circulation at the elbow, though urgent management may still be required. The AAOS guideline recommends that displaced paediatric supracondylar humerus fractures with decreased hand perfusion should be treated urgently with closed reduction [67]. The AAOS guideline also advises that open exploration of the antecubital fossa should be conducted in patients exhibiting absent wrist pulses and underperfusion following the reduction and pinning of displaced paediatric supracondylar humerus fractures (Figure 10.). Conversely, if the hands are pale and cold, immediate surgical intervention is mandatory [84, 85].

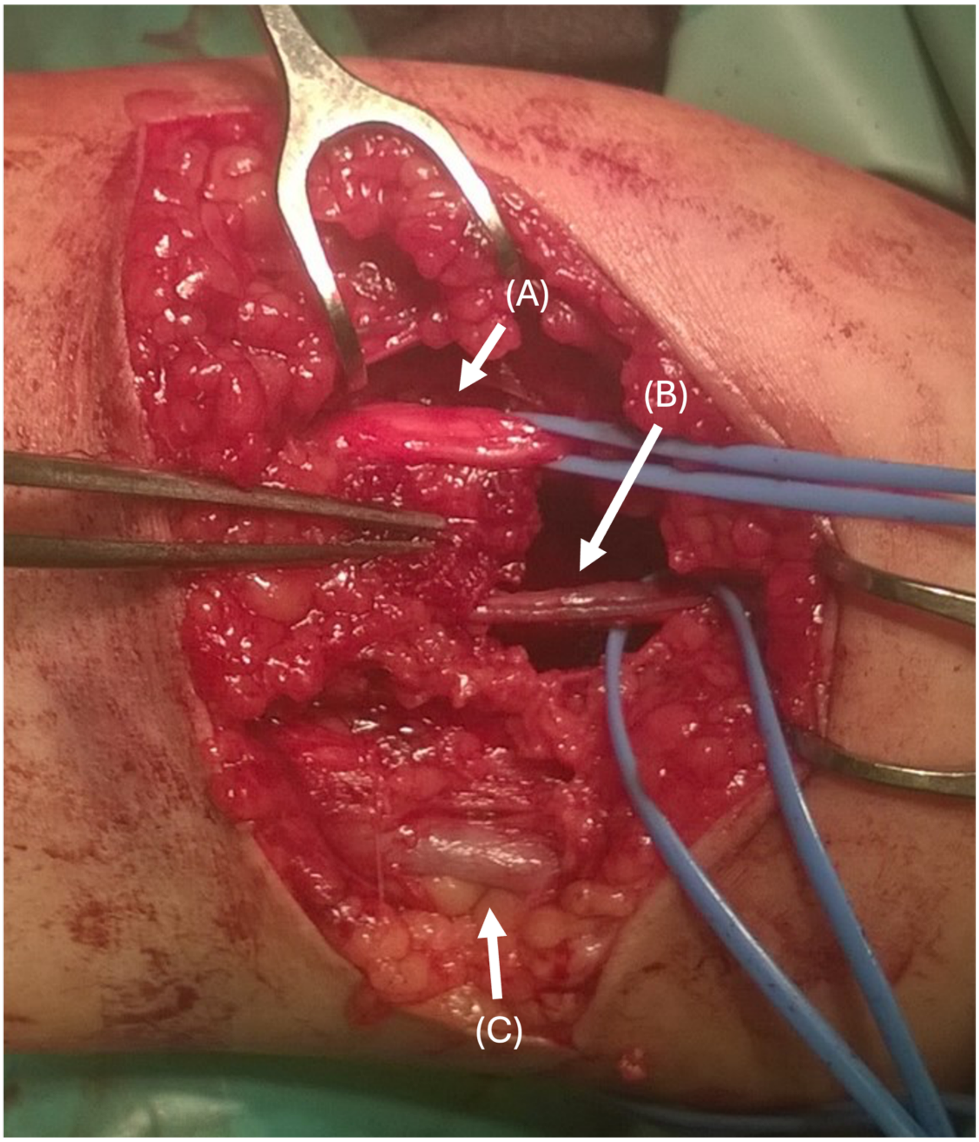

Figure 10. *Exploration of the antecubital fossa. (A) indicates the median nerve, (B) highlights the brachial artery, (C) points to the cephalic vein, and the forceps is targeting the brachial muscle.*

For displaced and closed SCHFs, the preferred surgical strategy involves closed reduction followed by the insertion of 2 mm wide lateral or crossed percutaneous K-wires (Kirschner-wires/pins) [86, 87]. At least two pins are necessary to ensure rotational stability, though the optimal placement—whether two or three lateral wires, or a mix of medial and lateral pins—is still debated [88] (Figure 11.). Crossed K-wires offer biomechanical advantages against torsional forces, but due to a high risk of iatrogenic ulnar nerve injury, an open medial incision is often recommended [89]. In rare cases elastic intramedullary nailing might be a good alternative.

Figure 11. *AP (A) and lateral (B) radiograph of a Gartland IV SCHF fracture. (C) and (D) shows the same fracture after open reduction and crossed pinning.*

For enhanced stabilization, lateral external fixation (fixateur externe) may be employed [90]. Conditions such as open wounds or entrapped neurovascular tissue require open reduction using similar pinning methods [91]. A ventral incision is preferred as it provides access to potentially injured nerves or vessels, although radial, ulnar, and dorsal approaches are also viable [92].

Post-operatively, pulseless, pale hands should be examined with Doppler ultrasound to confirm the absence of pulse, indicating a need for immediate vascular exploration [93]. For intimal tears, primary reconstruction might be appropriate, while larger lacerations and thrombosed arteries might necessitate angioplasty or a (saphenous) graft bypass [94]. The increased likelihood of compartment syndrome following vascular surgery may necessitate a fasciotomy [95].

3.4. Potential Complications from LHBT and SCHF Injuries and Treatments

3.4.1. LHBT Injuries and Treatments

In the literature, the most common complications after tenotomy are Popeye deformity, weakness, cramping pain, continued anterior shoulder pain and fatigue with use [72, 96, 97]. The study of Mirzayan et al. [97] reported that patients with active workers' compensation claims were found to have 12.5 times the odds of experiencing continued postoperative anterior shoulder pain. The same study [97] reported that every 10-year increase in age was associated with 0.52 times the odds of continued anterior shoulder pain and 0.59 times the odds of cramping pain.

The most frequently reported complications following tenodesis include anterior shoulder pain, weakness, cramping pain, cosmetic deformity or loss of fixation [74, 82]. Less common issues are for example infection, nerve injuries or fractures [72, 96]. However, in a study that examined complications after tenodesis in 1,526 shoulders [82], only one fracture was identified, and it was likely unrelated to the tenodesis procedure.

The method of fixation can influence the complications that arise; for instance, implant tenodesis is more likely to lead to revision surgery compared to soft-tissue tenodesis [82]. Additionally, patients who undergo soft-tissue tenodesis are significantly more likely to report subjective weakness postoperatively than those who have implant tenodesis [82]. Revision rates can vary depending on the surgical technique employed [74].

3.4.2. SCHF Injuries and Treatments

Many complications arise from the trauma itself, rather than the interventions; however, iatrogenic complications can also occur. Acute complications encompass compartment syndrome, vascular issues from brachial artery damage (such as pulseless pink hand or ischemic hand), or neurological deficits [98]. The likelihood of accidental ulnar nerve damage is significantly greater with cross pinning compared to lateral pinning [99]. Skin irritation, wound healing problems, decreased range of motion can also be seen. Wound infections are uncommon, whether the reduction is open or closed. Typically, these infections are superficial and can be effectively treated with local dressings and oral antibiotics, however, there is a possibility for the infection to spread into the elbow joint [100]. According to research by Ezeokoli et al., infection following CRPP (Closed Reduction and Percutaneous Pinning) is most commonly linked to typical pathogens and to wet casts [42]. Generally, a more severe fracture is associated with a higher risk of complications compared to a less severe fracture [41]. Chronic bone-related complications primarily involve malunion, which may result in deformities such as cubitus varus or cubitus valgus [98]. According to the literature, Volkmann's contracture can occur, though it is very rare and generally preventable [101].

Conservative treatment risks include improper bone healing, leading to deformity or functional impairment if the fracture is not adequately immobilized [98].

3.4.3. Long-term Outcomes

3.4.3.1. LHBT

Generally all treatment modalities result in excellent patient-reported outcomes [73]. Several studies highlight the advantages of tenodesis [102–107], whereas other research indicates no significant differences in functional outcomes between tenotomy and tenodesis [75, 76, 108–112]. Popeye deformity is more commonly observed in patients undergoing tenotomy, and younger patients express significantly lower satisfaction with such results [113].

Numerous outcome measures are available for evaluating the effectiveness of shoulder interventions and the overall condition of the shoulder.

The Constant score is a commonly used scoring system for assessing postoperative function following shoulder surgeries. Although it is not tailored specifically to biceps function, it was developed to evaluate the general functional status of the shoulder [114]. This score includes subjective elements like pain assessment and the ability to perform daily activities, as well as objective measures that evaluate the shoulder's range of motion and strength.

The American Shoulder and Elbow Surgeons (ASES) score [115] is a comprehensive tool used to assess the functional status of the shoulder, primarily employing a patient self-reported version in common practice. This method focuses on pain and daily activity levels, with the score equally divided between pain assessment and functional ability, each accounting for 50% of the total score.

The Simple Shoulder Test (SST) score [116] evaluates shoulder function through 12 patient-reported questions, focusing on pain, daily activities, and mobility to assess overall shoulder health and capability.

3.4.3.2. SCHF

Long-term subjective outcomes are generally satisfactory [98], especially if elbow range of motion and carrying angle are restored to within 10 degrees of the uninjured elbow [117]. Radiographs taken at the time of fracture union offer little prognostic value. Nerve injuries may lead to long-term pain [117, 118].

3.5. Unique Aspects of Paediatric elbow Injuries

Paediatric upper limb injuries, particularly SCHFs, present unique challenges due to the anatomical, physiological, and developmental characteristics of children. The bone structure of a child significantly differs from that of an adult in various crucial aspects. Children's bones are still growing, which is both an advantage and a risk. Paediatric bones are less dense, more porous, and contain fewer minerals. They are also more elastic and flexible, allowing them to deform more extensively before fracturing [58].

The immature skeleton is primarily characterized by the presence of growth plates and a thick periosteum. Growth plates are situated at the ends of long bones, driving their longitudinal development. Fractures near these plates in younger children have a high capacity for remodelling, allowing the physis of a misaligned bone to grow unevenly and realign itself over time. The degree of correction achievable through remodelling varies with the child's age and can address different levels of displacement and angulation, though not axial malrotation [58]. The presence of growth plates makes paediatric fractures more complex due to the risk of growth disturbances. Fractures affecting the growth plate can lead to premature closure, resulting in potential limb length discrepancies or angular deformities as the child grows [49].

The distal end of the humerus accounts for about 20% of the longitudinal growth of the humerus [49]. Therefore, SCHFs have a relatively low remodelling capacity compared to many other regions, making proper alignment and stabilization especially important.

The periosteum in children is robust, thick, and highly osteogenic, providing stability, limiting displacement, maintaining blood flow, ensuring the bone stays aligned, and enhancing the speed of fracture healing [58]. These factors significantly influence both the treatment approach and the long-term implications of these injuries.

3.6. Aims

3.6.1. LHBT Injuries

Previous meta-analyses comparing tenotomy and tenodesis for LHBT surgeries have either failed to reach a conclusive result [119] or included cohort studies [73, 120–125]. Significant debate persists, with no clear consensus on which procedure offers superior long-term benefits in terms of strength, flexibility, and pain relief. Consequently, in our study we focused on investigating these aspects. Our research also examines the cosmetic outcomes of each surgical option, with a particular focus on the development of Popeye deformity, which is vital for patient satisfaction and psychological well-being.

Given the mixed results from clinical trials and the limitations of prior meta-analyses, our goal was to conduct the most thorough analysis to date, comparing tenodesis and tenotomy in the treatment of LHBT disorders.

3.6.2. SCHF in Children

Many studies on SCHFs involve small sample sizes and utilize retrospective data collection, which can introduce significant bias. Our research sought to analyse the characteristics of children with SCHF recorded in our registry. We compared their demographic distribution and the outcomes of the interventions they received with those reported in the international literature.

4. Studies

4.1. Comparing the results of tenotomy and tenodesis in long head of the biceps tendon (LHBT) surgeries

4.1.1. Methods

We reported our research using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [126]. This provides a detailed checklist of items that should be reported when conducting and publishing systematic reviews and meta-analyses. Following the PRISMA guidelines helps ensure the transparency, reproducibility, and accuracy of our study.

Our research protocol was registered in advance on PROSPERO with the registration number CRD42021244613. There were no deviations from the protocol. Registering our study protocol in PROSPERO offers a detailed record of our study's design, objectives, and methods, along with any changes made during the study. This registration underscores our dedication to transparency and the reduction of potential bias in our research.

4.1.1.1. Search strategy, inclusion, and exclusion criteria

When framing our clinical question, we applied the PICOTS framework. The population (P) consisted of patients who underwent LHBT operations. The intervention (I) was tenotomy, and the comparison (C) was tenodesis. The outcome measures included pain on the ten-point Visual Analog Scale (VAS), events of bicipital cramping and bicipital groove pain, Constant score (range: 0–100), American Shoulder and Elbow Surgeons (ASES) score (range: 0–100), Simple Shoulder Test (SST) score (range: 0–12), operative time in minutes, elbow flexion strength, forearm supination strength, and Popeye deformity events. Timing (T) for statistical analysis of each outcome was set when at least three studies reported the same outcome at the same time point. Outcomes not suitable for quantitative synthesis were included solely in the systematic review section. The study type (S) comprised randomized controlled trials (RCTs).

On November 28, 2020, we conducted a systematic search across several databases: MEDLINE (via PubMed), Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and Scopus, using the search key: “bicep* AND teno*”. We utilized the “all fields” option in the first four databases, and in Scopus, we searched using the “Article title, Abstract, Keywords” field without applying any filters.

Our inclusion criteria were randomized controlled trials comparing tenotomy and tenodesis and reporting on the specified outcomes.

Our exclusion criteria included reviews, meta-analyses, cohort studies, case reports, descriptions of surgical techniques, studies comparing different tenodesis techniques, distal biceps tears, biomechanical studies, cadaver studies, and animal studies.

4.1.1.2. Selection and data extraction

We utilized EndNote X9 (Clarivate Analytics, Philadelphia, PA, USA) for the selection process. Following the removal of duplicates, two independent authors (M.V., L.S.) carried out the selection, initially by title, then by abstract, and finally by full text.

At each stage of the selection, we calculated Cohen's kappa to evaluate the agreement between the two reviewers, with parameters set as follows: 0.00–0.20 indicated no agreement, 0.21–0.39 minimal agreement, 0.40–0.59 weak agreement, 0.60–0.79 moderate agreement, 0.80–0.90 strong agreement, and above 0.90 almost perfect agreement [127]. We also checked the references of the qualified records for any additional articles to include in the meta-analysis.

The same reviewers (M.V., L.S.) performed data extraction using a predefined Excel sheet (Office 2016, Microsoft, Redmond, WA, USA). We collected data on the first author, publication year, country, study design, demographic information, surgical indication, surgical techniques, and reported outcomes. If strength measurements were reported in Newtons (N), we converted these to kilograms (kg) using an online calculator (calculator-converter.com). If the studies reported strength measurements for both sides but not the Strength Index (SI), we calculated the SI from these measurements.

Any disagreements in both the selection and data extraction processes were resolved by consensus between the two review authors (M.V., L.S.).

4.1.1.3. Statistical analysis

For dichotomous outcomes, we calculated odds ratios (ORs) with their 95% confidence intervals (CIs) from the original raw data of the articles. We applied a continuity correction [128] for the calculation of bicipital cramping pain events, when no events were reported in some studies. For continuous outcomes, we computed weighted mean differences (WMDs) with 95% CIs from the original data, except in cases where means and standard deviations (SDs) were derived from the minimum, median, maximum, and sample size using Wan's method [129]. We used the random effects model by DerSimonian and Laird [130] across all analyses, incorporating an estimate of heterogeneity. According to the Cochrane Handbook, I^2

values indicated moderate heterogeneity at 30-50%, substantial heterogeneity at 50-75%, and considerable heterogeneity above 75%. Results were visually presented using forest plots.

We conducted a trial sequential analysis (TSA) [131] when statistically feasible to confirm the reliability of our data, calculating the required information size and adjusting for significance in cases of sparse data.

Statistical analysis and comparison of each outcome were conducted when at least three studies reported data at the same time point. We presented individual results from all included studies in the systematic review section to compare the two surgical methods transparently.

All data management and statistical analysis were executed using Stata (version 16.0, StataCorp) and the TSA software from the Copenhagen Trial Unit, Centre for Clinical Intervention Research, Denmark.

4.1.1.4. Risk of bias assessment and quality of evidence

We conducted a risk of bias assessment for each analysed outcome using the RoB 2: A revised Cochrane risk of bias tool for randomized trials [132], in line with Cochrane recommendations.

To evaluate the certainty of the evidence, we employed the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system [133], categorizing our findings into four levels of certainty: high, moderate, low, and very low.

Two independent review authors (M.V. and L.S.) carried out both the risk of bias and the certainty of evidence assessments. Any disagreements were resolved through consensus.

4.1.2. Results

4.1.2.1. Search and selection

Figure 12 illustrates the summary of our selection process, including Cohen’s kappa for each stage. We initially identified 5,450 records across five databases. Upon completing the selection process, we identified nine full-text articles eligible for the meta-analysis [134–142] and eleven studies for inclusion in the systematic review section [134–144].

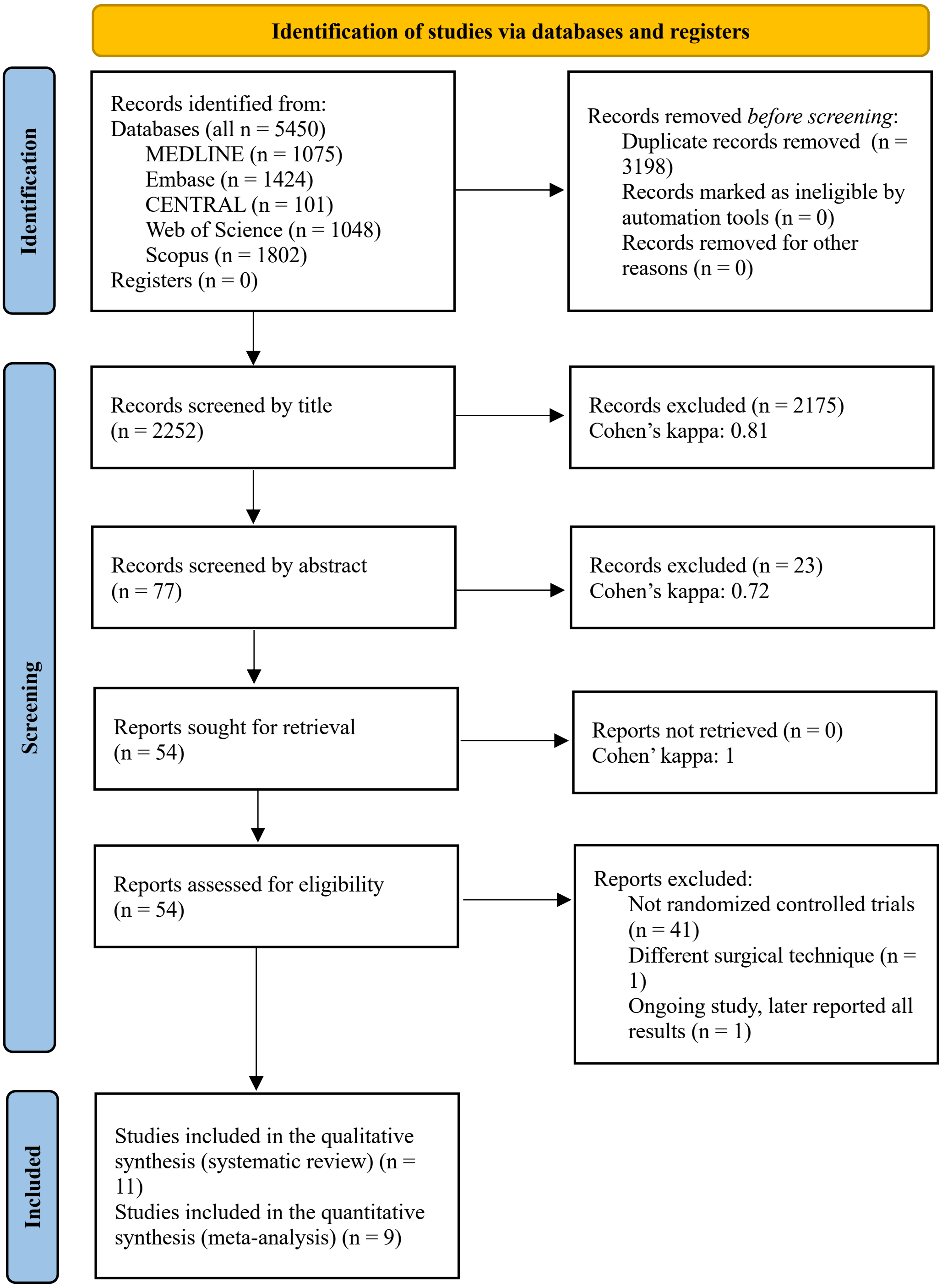

Figure 12. *A Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow chart that represents the search and selection process.*

4.1.2.2. Characteristics of the studies included

Supplementary Table 1 presents the basic characteristics of the included studies, all of which were RCTs. Our meta-analysis included nine studies and 572 participants, with 293 in the tenotomy group and 279 in the tenodesis group. Two studies [143, 144] did not report outcomes at comparable time points, thus were only included in the systematic review section.

All studies involved patients with LHBT pathology. Nine of the eleven studies [135–137, 139–144] also included patients with concurrent rotator cuff tears, whereas two studies [134, 138] specifically excluded such patients.

Tenotomy was performed arthroscopically in all studies. Tenodesis was also carried out arthroscopically, except in 31.5% of patients (17 out of 54) in the study of MacDonald et al. [139], where an open sub-pectoral approach was used.

The follow-up periods varied among the studies, generally ranging from 12 to 24 months, with some differences in the evaluation times for various outcomes.

4.1.2.3. Meta-analysis results

4.1.2.3.1. Post-operative function

At the 6-month follow-up, the analysis of elbow flexion strength in kilograms showed no statistically significant difference [136, 138, 139] (WMD: 2.82; 95% CI: -1.79 to 7.22; $p = 0.237$; $I^2 = 71.7\%$; evidence graded as low) (Supplementary Figure 1.). However, at the 12-month follow-up, elbow flexion scores in kilograms indicated a statistically significant difference favouring tenodesis [137–139] (WMD: 3.67; 95% CI: 1.07 to 6.27; $p = 0.06$; $I^2 = 36.6\%$; evidence graded as moderate) (Figure 13.). Similarly, analysis of forearm supination strength at 12 months also revealed a statistically significant difference [137–139] (WMD: 0.36; 95% CI: 0.08 to 0.64; $p = 0.012$; $I^2 = 7.2\%$; evidence graded as low) (Figure 14.).

We analysed the Constant score from three studies at the 6-month follow-up [136, 138, 140] (WMD: 0.78; 95% CI: -2.44 to 4.00; $p = 0.634$; $I^2 = 27.7\%$; evidence graded as moderate) (Supplementary Figure 2.) and from three studies at the 12-month follow-up [137, 138, 140] (WMD: 2.26; 95% CI: -1.12 to 5.65; $p = 0.190$; $I^2 = 59.1\%$; evidence graded as low) (Figure 15.). Neither analysis showed a statistically significant difference between the two groups. Additionally, although Lee et al. [143] reported 6-month and 12-month Constant scores, these outcomes were not analysed due to insufficient data (the results are displayed on a graph, making precise data collection at different time points impossible).

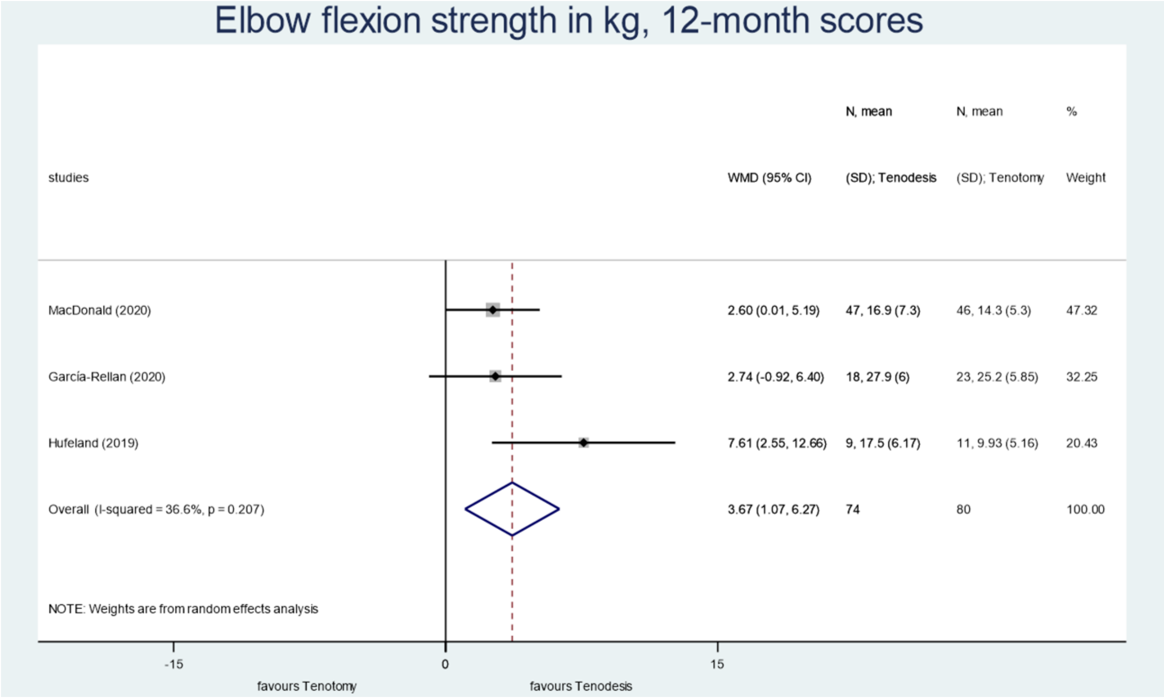

Figure 13. *A Forest plot representing the results of elbow flexion strength measurements in kg, comparing tenotomy and tenodesis at the 12-month follow-up. The black diamonds represent the effect of individual studies, and the vertical lines show the corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.*

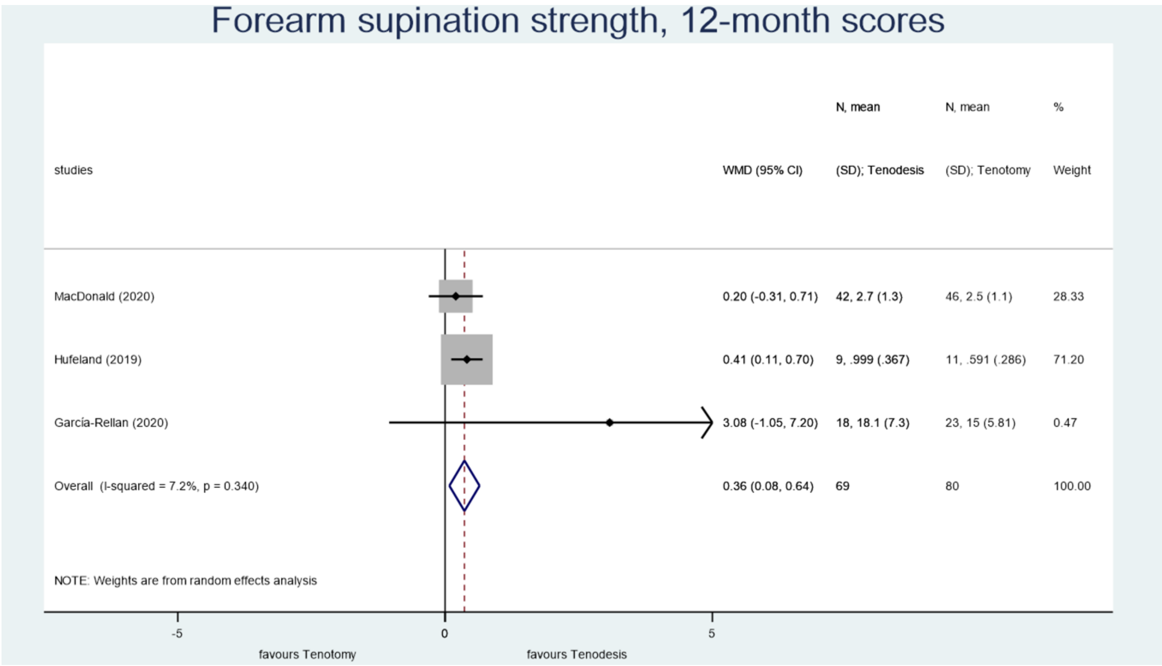

Figure 14. *A Forest plot representing the results of the 12-month forearm supination strength levels in kg, comparing tenotomy and tenodesis.*

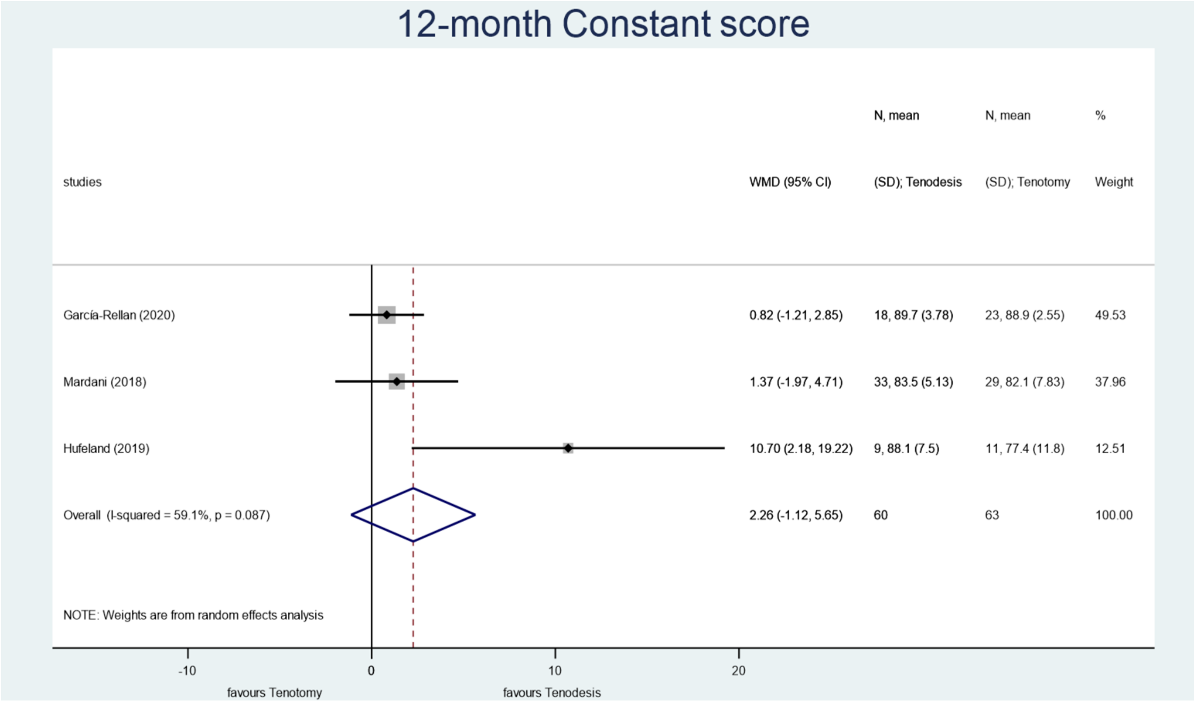

Figure 15. *A Forest plot representing the 12-month Constant scores, comparing tenotomy and tenodesis.*

4.1.2.3.2. Post-operative pain

Three studies assessed 3-month pain scores using the ten-point Visual Analog Scale (VAS) [134, 135, 139] (WMD: 0.99; 95% CI: 0.51-1.48; $p < 0.001$; I^2=0.0%; evidence graded as high) (Figure 16.). The results showed a significant difference in favour of tenotomy, suggesting earlier pain relief with tenotomy compared to tenodesis. At the 6-month [134, 136, 139, 140] (WMD: 0.05; 95% CI: -0.21 to 0.30; $p = 0.724$; I^2=0.0%; evidence graded as moderate) (Supplementary Figure 3.), 12-month [134, 137, 139, 140] (WMD: 0.19; 95% CI: -0.26 to 0.63; $p = 0.411$; I^2=80.1%; evidence graded as very low) (Figure 17.), and 24-month [135, 136, 139, 140] (WMD: 0.01; 95% CI: -0.04 to 0.07; $p = 0.637$; I^2=0.0%; evidence graded as moderate) (Supplementary Figure 4.) follow-ups, pain scores revealed no significant differences. Lee et al. [143] also reported 3-month, 6-month, and 12-month pain levels, but these could not be analysed due to data limitations.

Additionally, the analysis of bicipital cramping pain events at 6 months [136, 138, 141] revealed no significant difference (OR: 0.92; 95% CI: 0.09-9.07; $p = 0.943$; I^2=47.8%; evidence graded as moderate) (Supplementary Figure 5.).

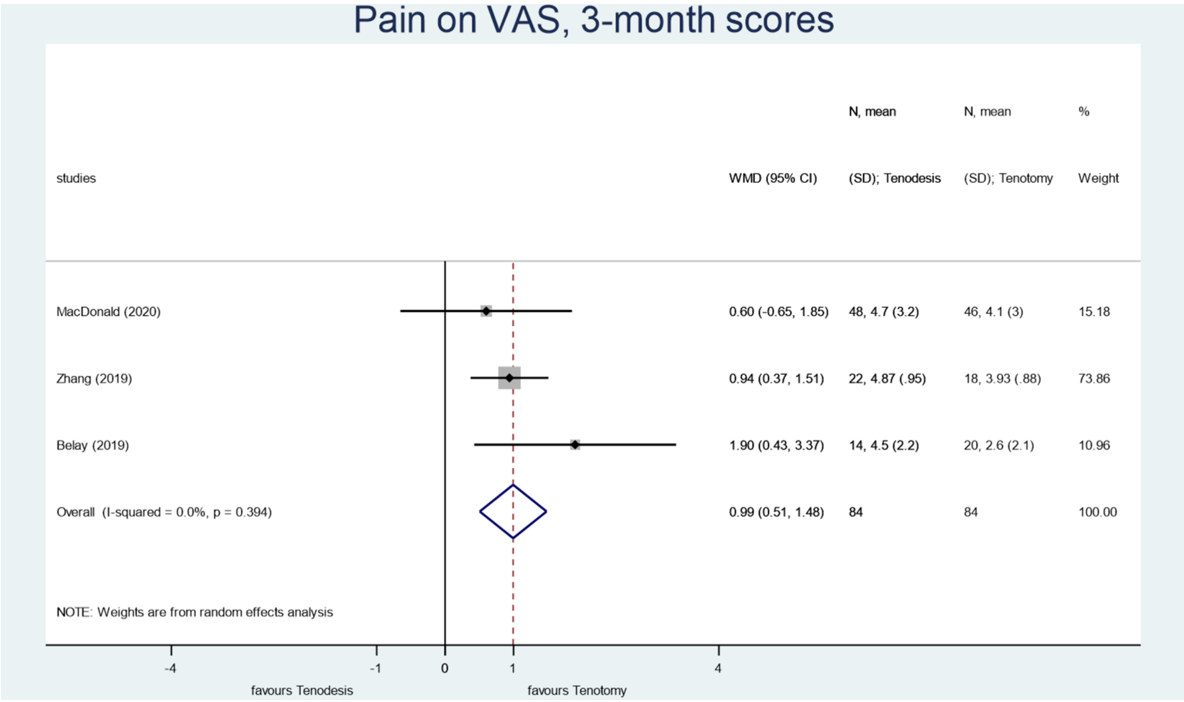

Figure 16. *A Forest plot representing the level of postoperative pain on the Visual Analog scale (VAS), comparing tenotomy and tenodesis, measured 3 months postoperatively.*

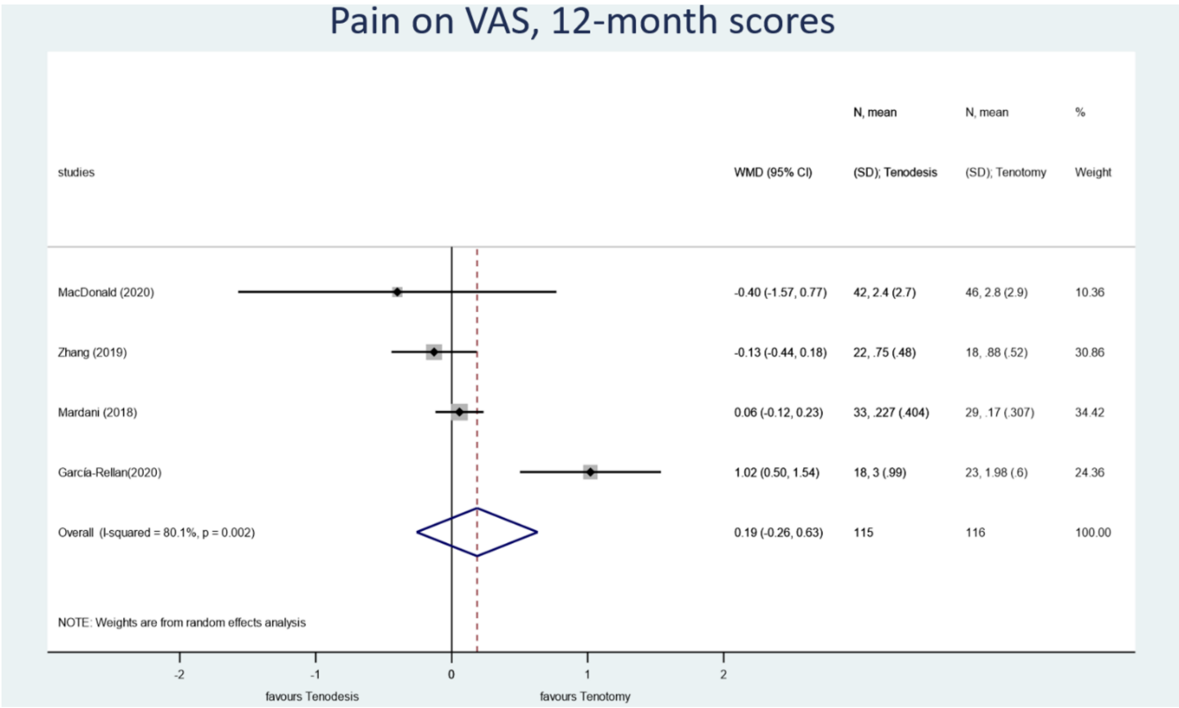

Figure 17. *A Forest plot representing the level of pain on the Visual Analog Scale (VAS), comparing tenotomy and tenodesis at the 12-month follow-up.*

4.1.2.3.3. Popeye deformity

Three studies [136, 139, 140] reported on the incidence of Popeye deformity at the 24-month follow-up. There was a significant difference between tenotomy and tenodesis, favouring tenodesis in this outcome (OR: 0.19; 95% CI: 0.08-0.41; $p < 0.001$; I^2=0.0%; evidence graded as moderate) (Figure 18.).

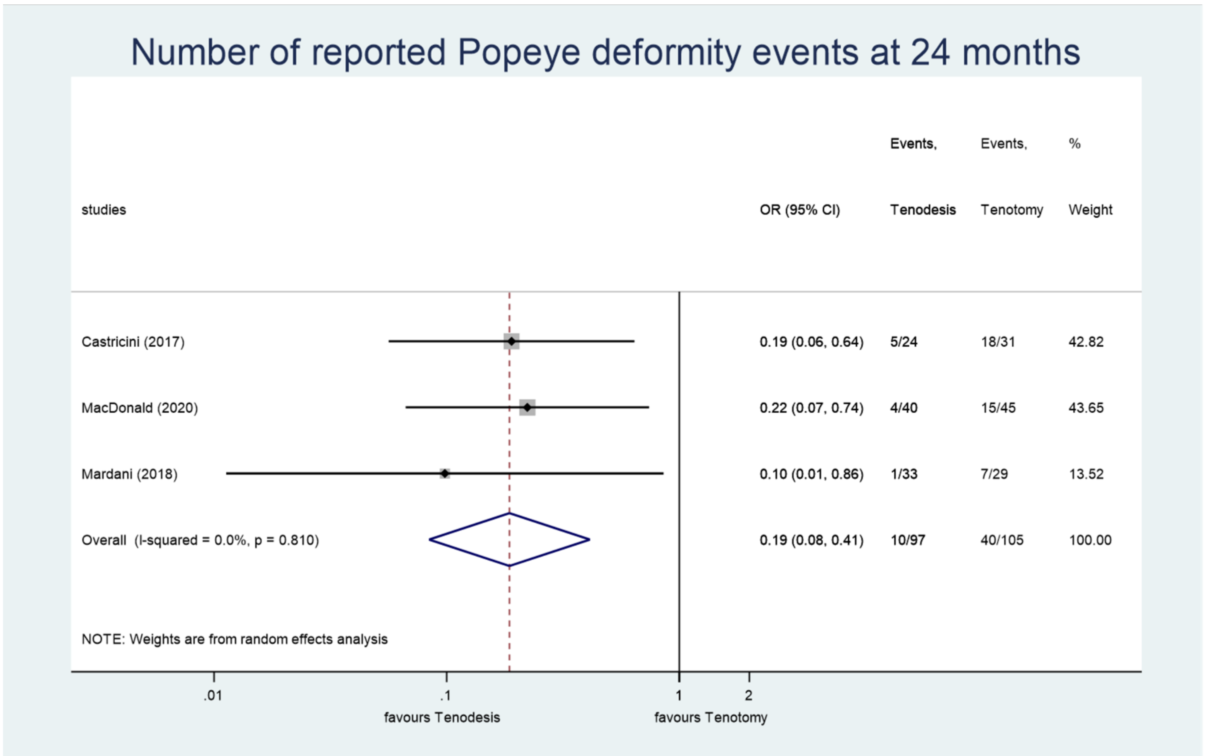

Figure 18. *A Forest plot representing the occurrence of Popeye deformity, comparing tenotomy and tenodesis, measured 24 months postoperatively.*

4.1.2.3.4. Operative time

When comparing the operative times (in minutes) for tenotomy and tenodesis, no statistically significant differences were observed [134, 139, 142] (WMD: 17.15; 95% CI: -2.05 to 36.35; $p = 0.080$; I^2=97.5%; evidence graded as very low) (Figure 19.).

4.1.2.3.5. TSA (Trial Sequential Analysis)

Our Trial Sequential Analysis (TSA) results are shown in Supplementary Figures 6-13. However, TSA could not be conducted for certain outcomes due to insufficient data, specifically the 6-month Constant scores, 6-month VAS pain scores, 24-month VAS pain scores, and bicipital cramping pain events at 6 months postoperatively.

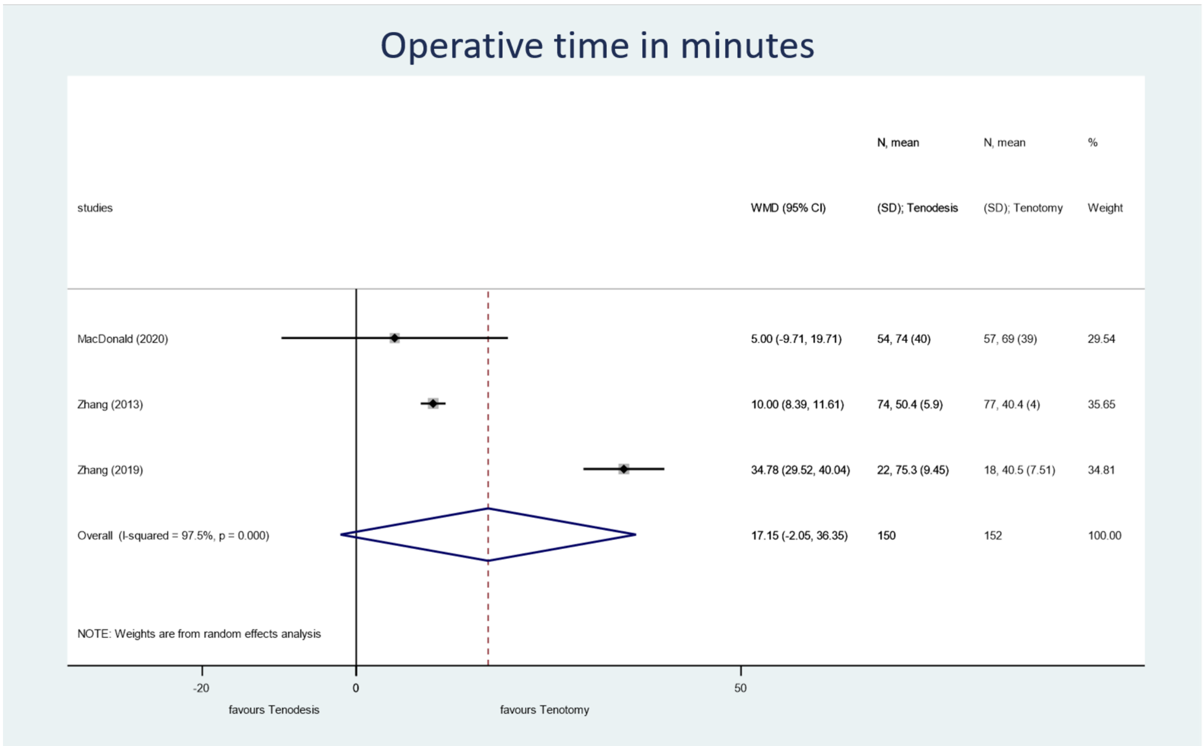

Figure 19. *A Forest plot that compares the operative time of tenotomy and tenodesis.*

4.1.2.4. Systematic review results

Eight studies measured elbow flexion strength [136–139, 141–144], six assessed forearm supination strength [137–139, 141–143], and seven evaluated the Constant score [136–138, 140, 142–144]. Five studies included the ASES score [135, 138, 139, 141, 143], while three reported on SST scores [138, 140, 144]. Pain levels were reported by nine studies [134–137, 139–143], the incidence of bicipital cramping pain was noted in six [136–138, 140–142], and bicipital groove pain events were reported in three studies [135, 137, 141]. All studies included data on Popeye deformity outcomes [134–144]. Lee et al. [143] provided data on the Constant score, ASES score, and pain levels at 3, 6, 12 months, and final follow-up, but these could not be analysed due to insufficient data.

Supplementary Table 2 summarizes the calculated odds ratios and weighted mean differences for outcomes that were not suitable for meta-analysis.

4.1.2.5. Risk of bias assessment and quality of evidence

The risk of bias assessment is detailed on Figure 20, and Supplementary Figures 14-34. Popeye deformity was reported across all studies. In this assessment, four studies were found to have a high risk of bias [134, 140, 143, 144], six studies raised "some concerns" [135–138, 140, 142], and one study was determined to have a low risk of bias [139]. Lower grades were generally due to unclear randomization processes, lack of blinding, and missing trial protocols.

Number of Popeye-deformity, final scores						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Belay 2019	+	+	+	!	!	!
Castricini 2017	+	+	+	+	!	!
DeCarli 2012	!	+	+	!	!	-
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Lee 2016	!	+	!	+	!	-
MacDonald 2020	+	+	+	+	+	+
Mardani 2018	!	+	+	!	!	-
Oh 2016	!	+	+	+	!	!
Zhang 2013	+	+	+	+	!	!
Zhang 2019	!	+	+	!	!	-

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the process resulted in three or more yellows or any reds.

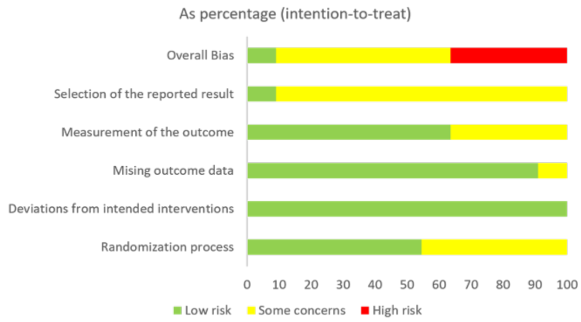

Figure 20. *Risk of bias assessment of the number of Popeye deformity events at the final evaluation outcome.*

The results of the GRADE analysis for each outcome are presented in the results section, with a comprehensive description of the evidence quality provided in Supplementary table 3.

4.1.3. Discussion

Previous meta-analyses included non-randomized trials [73, 120–125], except for Ahmed et al. [119]; therefore, their results should be approached with caution.

The biceps brachii plays a crucial role in elbow flexion strength. For this reason, we chose it as one of our primary outcome parameters. Although there was no significant difference at the 6-month follow-up, the 12-month results showed significantly better elbow flexion strength in the tenodesis group. This finding is novel compared to previous meta-analyses that have examined this outcome [119, 120, 122, 124, 125]. However, our TSA indicates that more RCTs are needed for the 6-month results, and despite reaching the required sample size for the 12-month results, the potential for spurious significance means these findings are inconclusive according to TSA. The individual study results included in the systematic review are mixed, and due to varying time points, further statistical comparisons could not be performed.

Another key function of the biceps brachii is forearm supination. Our results indicated a statistically significant difference at 12 months in favour of tenodesis, which contradicts existing literature [119, 120, 122, 124, 125]. Our TSA suggests that additional clinical trials are necessary to establish more definitive results. Analysis of final data from individual studies showed a tendency favouring tenodesis regarding this outcome.

We observed no significant differences in Constant scores at 6 and 12 months post-operatively. However, adding systematic review results indicates a trend where tenodesis may lead to better post-operative scores than tenotomy. This aligns with previous meta-analyses, which either identified statistically significant differences without reaching the minimal clinically important difference (MCID) [73, 119–121, 123–125] or found no significant differences between the two methods [122] [37].

From a patient perspective, post-operative pain is a critical quality measure. Our analysis of VAS scores at 3, 6, 12, and 24 months after surgery found a significant difference only at 3 months in favour of tenotomy. The TSA for this outcome indicated that no further studies are needed to confirm this result, suggesting that patients experience less pain three months after tenotomy compared to tenodesis. Long-term results showed no significant differences between the methods. Other meta-analyses examining VAS pain [119, 120, 124, 125] did not find significant differences at multiple time points, and systematic review results did not show a clear preference for either method.

Previous studies suggest that tenotomy may lead to a higher incidence of cramping pain events [121, 122], but our 6-month results do not support this claim and align with analyses finding no difference between the methods [73, 119, 120, 123–125].

In a recent study involving 1,723 patients, tenotomy was associated with a higher incidence of Popeye deformity compared to tenodesis [106]. Our findings confirm this, with a significant difference favouring tenodesis, consistent with earlier meta-analyses [73, 119–125]. The TSA indicated that no further clinical trials are needed to confirm this result.

Surgical times vary due to factors like concurrent procedures and the experience of the surgical team. Although previous systematic reviews and meta-analyses suggest that tenotomy generally has shorter operative times [121], interestingly, despite all included RCTs indicating that tenodesis takes longer to perform [134, 139, 142], our analysis revealed no statistically significant difference in duration between tenotomy and tenodesis. Given the established literature and conflicting TSA results, no definitive conclusion can currently be drawn on this topic.

4.1.3.1. Strengths and Limitations

This meta-analysis, incorporating nine studies, has significant strengths. It employs a stringent methodology, with outcomes assessed at consistent time points across studies. By including only randomized controlled trials, this analysis represents the highest level of evidence available on this subject. Trial sequential analyses were conducted to determine the necessity of additional clinical trials, and findings regarding three-month pain levels on the VAS and Popeye deformity at the 24-month follow-up were deemed conclusive.

However, our meta-analysis also faced some limitations, such as small sample size that affected some TSA results. Additionally, there were variations in treatment indications among the included trials, as well as differences in intervention submodalities and rehabilitation protocols. In some instances, standard deviations and means were derived from the minimum, median, maximum, and sample sizes. The TSA did not provide conclusive results for outcomes like 6-month elbow flexion strength, 12-month elbow flexion strength, 12-month forearm supination strength, 12-month Constant score, 12-month VAS pain levels, and operative time.

We recommend further randomized controlled trials focusing on elbow flexion strength, forearm supination strength, pain, and operative time, as these outcomes were inconclusive based on our TSA. Future RCTs should specify exact time points for outcome assessments and prioritize biceps function-specific outcomes such as flexion and supination strength. The use of the LHB score [145, 146], which is specific to biceps function, might be advantageous in studies targeting LHBT treatment methods, in contrast to more general scoring systems such as Constant, ASES, SST, and UCLA (University of California at Los Angeles). Additionally, creating and reporting subgroups, such as those with or without concomitant rotator cuff surgery or comparing different tenotomy methods with the potential for autotenodesis, would enhance the specificity and relevance of the findings.

4.1.3.2. Conclusions

Our findings suggest that tenodesis is preferable to tenotomy due to its association with a lower incidence of Popeye deformity, improved postoperative biceps function, and comparable long-term pain outcomes.

4.2. The first analysis of a multicentre paediatric supracondylar humerus fracture (SCHF) registry by fracture type

4.2.1. Materials and methods

We employed the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guideline to present our research [147], which provides a framework for reporting observational studies, enhancing transparency and quality in research by specifying necessary information to include in study reports.

The registry received ethical approval from the Scientific and Research Ethics Committee of the Medical Research Council (35335-2/2018/EKU).

4.2.1.1. Data source and quality

Data that were prospectively collected into the Hungarian paediatric SCHF Registry were analysed retrospectively, which includes data from seven institutions about patients who underwent surgery between September 5, 2018, and March 25, 2021.

To maintain high data quality, all information added to the registry underwent a four-tier quality assurance process conducted by both administrators and surgeons.

4.2.1.2. Categorization by fracture type

The operating surgeon classified each fracture using anteroposterior and lateral radiographs, making a Gartland IV categorization infeasible as it requires an intraoperative diagnosis. Three fracture types were identified: Gartland type IIA (where displacement occurs in one plane, but the fragments remain connected), Gartland type IIB (which includes rotational displacement with some bone still connecting the ends), and Gartland type III (where no connection exists between the bone fragments). Analysis of different outcomes were made by creating and comparing three groups based on these fracture types.

4.2.1.3. Analysed endpoints

We aimed to statistically assess various parameters to identify potential differences among the three groups, including age, sex, body mass index (BMI), type of injury (flexion vs. extension), radial pulse and oxygen saturation at the initial examination, as well as outcomes from the hand function assessment. Additional evaluations included pre- and postoperative antibiotic use, the surgeon's level of expertise (non-specialist, young specialist with less than 10 years of experience, or senior specialist with 10 years or more), methods of fracture reduction, type of open reduction, intraoperative fixation techniques, the number and diameter of pins used, intra- and postoperative analgesic use, pain medication prescribed for home, operative time, early complications (before hospital discharge), and late complications (after discharge, including during follow-up visits). Weeks until pin removal was also recorded. We defined complications as issues such as skin irritation, superficial infections, synovitis, wound healing problems, elbow swelling, fever, loss of movement, deep infection, vascular or neurological injuries, bone-related issues (misalignment, redislocation, delayed union, non-union), and compartment syndrome.

4.2.1.4. Statistical analysis

We compiled all the available data from the registry using an Excel sheet (Office 365, Microsoft, Redmond, WA, USA). All analyses were conducted using the R statistical software, version 4.0.2 (R Core Team, 2020, Vienna, Austria). We analysed differences between the groups using the Chi-Squared test or Fisher's Exact test for categorical variables. When significant differences were found, post hoc analysis was performed using Fisher's pairwise tests of independence for nominal data, with p-values adjusted by the FDR method for multiple comparisons (Benjamini–Hochberg false discovery rate). For continuous variables, the Kruskal-Wallis rank sum test was applied, followed by Dunn's post hoc test [148], using Holm-Šídák p-value correction to assess differences between groups.

A p-value of less than 0.05 was considered statistically significant, except in Dunn's post hoc test, where a p-value of less than 0.025 was deemed significant.

We analysed data from nearly all registered patients (214 out of 217); thus, a representativeness analysis was not necessary. The registry included data on 217 patients, but three were excluded from the comparative analysis due to unavailability of fracture classification.

4.2.2. Results

4.2.2.1. Preoperative data summary

The dataset included 217 patients, with an average age of 6.52 years—6.08 for females and 7.03 for males. Among these, 53.46% (116) were female, and 46.54% (101) were male. We recorded 214 cases in the registry, classified into three Gartland groups: 31 in Gartland IIA, 121 in Gartland IIB, and 62 in Gartland III. A significant sex difference was observed (p=0.001), particularly between the Gartland IIA and Gartland IIB groups (p=0.0008) (Gartland IIA f/m: 2.58/7.42, vs. Gartland IIB f/m: 6.28/3.72) (Figure 21.).

Table 1. *Statistics and results of Gartland IIA, Gartland IIB and Gartland III groups*

	Gartland IIA (number of cases)	Gartland IIB (number of cases)	Gartland III (number of cases)
Age (years)	6.55 ± 2.54* (31)	6.40 ± 2.44* (121)	6.61 ± 2.50* (62)
Sex			
Female	25.81% (8)	62.81% (76)	51.61% (32)
Male	74.19% (23)	37.19% (45)	48.39% (30)
BMI#	16.34 ± 3.61* (28)	15.96 ± 3.07* (111)	17.18 ± 3.77* (48)
Type of injury			
Flexion	3.23% (1)	9.92% (12)	9.68% (6)
Extension	96.77% (30)	90.08% (109)	90.32% (56)
Initial radial pulse			
Palpable	100% (30)	91.67% (110)	85.48% (53)
Not palpable but good microcirculation	0	8.33% (10)	11.29% (7)
Not palpable and bad microcirculation	0	0	3.23% (2)
Initial oxygen saturation	98.29% ± 0.85* (17)	98.19% ± 1.28* (83)	96.78% ± 4.96* (36)
Initial hand function assessment			
Total function	81.48% (22)	67.83% (78)	59.32% (35)
Could not be assessed objectively because of pain	18.52% (5)	30.43% (35)	38.98% (23)
Median nerve disfunction	0	0	1.69% (1)
Radial nerve disfunction	0	0.87% (1)	0
Ulnar nerve disfunction	0	0.87% (1)	0
Preoperative antibiotic use (yes)	86.12% (25)	90.08% (109)	94.74% (54)
Type of fracture reduction			
Closed	93.55% (29)	71.9% (87)	50% (31)
Closed using a percutaneous tool	3.23% (1)	11.57% (14)	16.13% (10)
Closed using the joystick method	0	0.83% (1)	0
Primarily open	3.23% (1)	9.09% (11)	24.19% (15)
Closed, then converted to open because of radial artery disfunction	0	2.48% (3)	3.23% (2)
Closed, then converted to open because of other reasons	0	4.13% (5)	6.45% (4)
Type of open reduction			
Ventral	0	42.11% (8)	61.9% (13)
Radial	0	21.05% (4)	19.15% (4)
Ulnar	100% (1)	21.05% (4)	4.76% (1)
Ventral and radial	0	5.26% (1)	9.52% (2)
Ventral and ulnar	0	5.26% (1)	4.76% (1)
Ventral, radial, and ulnar	0	5.26% (1)	0
Number of pins			
2	80.65% (25)	72.91% (83)	75.86% (44)
3	19.35% (6)	19.3% (22)	12.07% (7)
4	0	7.89% (9)	10.34% (6)
5	0	0	1.72% (1)
Intraoperative local analgesic use (yes)	38.71% (12)	52.07% (63)	54.1% (33)
Postoperative antibiotic use (yes)	3.23% (1)	4.13% (5)	12.7% (7)
Early complications			
No early complications	96.77% (30)	90% (108)	81.97% (50)
Neurological	3.23% (1)	8.33% (10)	14.75% (9)
Vascular	0	1.67% (2)	1.64% (1)
Bone-related	0	0.83% (1)	1.64% (1)
Late complications			
No late complications	88.89% (24)	80.53% (91)	80.33% (49)
Neurological	3.7% (1)	7.96% (9)	11.47% (7)
Vascular	0	0	1.64% (1)
Bone-related	0	4.42% (5)	1.64% (1)
Superficial infection	3.7% (1)	3.54% (4)	1.64% (1)
Deep infection	0	0.88% (1)	0
Wound healing problem	3.7% (1)	1.77% (2)	0
Pin protrusion	0	6.19% (7)	1.64% (1)
Loss of movement	0	4.42% (5)	0
Elbow swelling	0	1.77% (2)	0
Fever	0	0.88% (1)	0
Weeks until pins were removed	6.27 ± 4.76* (26)	5 ± 4.88* (106)	4.66 ± 1.29* (59)

***(mean ± SD) SD=Standard Deviation, BMI# = Body Mass Index**

The BMI of 190 patients was documented, averaging 16.36 (Figure 21.).

Oxygen saturation on the injured limb during the initial examination was recorded for 137 cases, with an average of 97.83%. Oxygen saturation was significantly lower in the Gartland III group compared to Gartland IIB (Gartland IIB mean 98.19%, Gartland III mean: 96.78%) (p=0.0110) (Figure 21.).

Out of 214 cases, 195 (91.12%) involved extension injuries and 19 (8.88%) involved flexion injuries.

Radial pulse at the initial examination was recorded for 215 cases: 196 (91.16%) were palpable, 17 (7.91%) were not palpable but showed good microcirculation, and two (0.93%) were not palpable with insufficient microcirculation (Figure 21.).

Hand function assessment results were available for 204 cases: 138 (67.65%) had full function, 63 (30.88%) were not objectively assessable due to pain, and three patients showed signs of nerve dysfunction—one each for the median (0.49%), radial (0.49%), and ulnar (0.49%) nerves.

Preoperative antibiotic use was documented for 210 patients: 190 (90.48%) received antibiotics, and 20 (9.52%) did not. Among those treated, the antibiotics used were cefazolin for 167 (87.89%), amoxicillin and clavulanic acid for 20 (10.53%), and clindamycin for three (1.58%).

Due to the small number of cases in certain subgroups, statistical analysis was not feasible for outcomes like radial pulse at the initial examination and results of hand function assessment.

There were no significant differences observed in age distribution (p=0.7934), BMI (p=0.2254), type of injury (flexion vs. extension) (p=0.5606), or preoperative antibiotic use (p=0.3533).

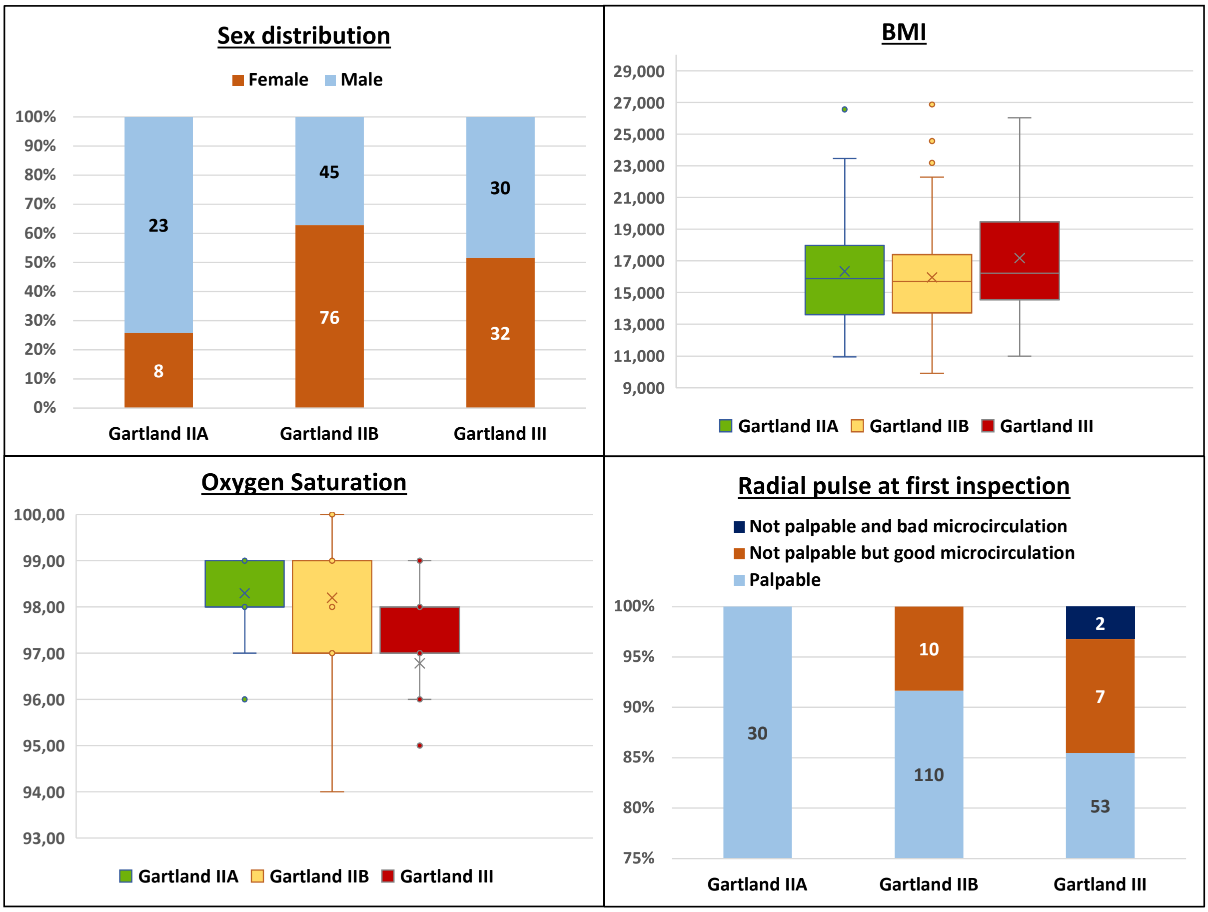

Figure 21. *Preoperative data by fracture type groups: a column chart comparing sex distribution, a box chart comparing BMI (body mass index), a box chart comparing oxygen saturation, and a column chart comparing radial pulse at first inspection. All comparisons are between Gartland IIA, Gartland IIB and Gartland III groups.*

4.2.2.2. Operative data summary

Out of 216 records, 102 patients were operated on by a senior specialist (47.22%), 59 by a junior specialist (27.31%), and 55 by a surgeon who is not yet a specialist (25.46%). There was a significant difference in the competence level of the surgeon (p=0.0228), but post-hoc analysis could not identify the specific groups responsible for this difference (Gartland IIA/Gartland IIB: p=0.0955, Gartland IIA/Gartland III: p=0.0633, Gartland IIB/Gartland III: p=0.0955) (Figure 22.).

The fracture reduction method was documented in all 217 cases. There were 150 closed reductions (69.12%), five that began closed but were converted to open due to radial artery dysfunction (2.3%), and nine that started closed but converted to open for other reasons (4.15%). Additionally, 25 reductions used a percutaneous tool (11.52%), one was performed using the joystick method with external fixateur rods or pins (0.46%), and 27 were primarily open surgeries without attempting closed reduction (12.44%) (Figure 22.).

Open reduction was necessary in 41 cases, with the following surgical approach distribution: 21 ventral (51.22%), 8 radial (19.51%), 6 ulnar (14.63%), 3 ventral and radial (7.32%), 2 ventral and ulnar (4.88%), and 1 involving ventral, radial, and ulnar approaches (2.44%) (Figure 22.).

Intraoperative fixation methods were documented in 207 cases: 204 used pinning (97.6%), 3 used external fixateur (1.44%), and 2 used intramedullary fixation (0.96%). Of the pinning cases, the number of pins used was: two in 153 cases (75%), three in 35 (17.16%), four in 15 (7.35%), and five in one case (0.49%). The pin diameters recorded in 194 patients were: 2 mm in 129 cases (66.49%), 1.8 mm in 35 (18.4%), 1.5 mm in 24 (12.37%), and 2.2 mm in six cases (3.09%). No significant differences were found among groups based on pin diameters ($p=0.1556$).

Intraoperative local analgesic use was recorded in 216 cases: administered in 109 patients (50.46%) and not administered in 107 (49.54%). There were no significant differences based on intraoperative local analgesic use ($p=0.3404$) between any groups.

In the 207 reported cases, the mean operative time was 48.19 minutes, ranging from 10 to 300 minutes. There was a significant difference in operative times between all groups (Gartland IIA/Gartland IIB: $p<0.005$, Gartland IIA/Gartland III: $p<0.005$, Gartland IIB/Gartland III: $p<0.005$), with average times of 29.3 minutes for Gartland IIA, 44.57 minutes for Gartland IIB, and 65.19 minutes for Gartland III (Figure 22.).

Due to the low sample size in many subgroups, correct statistical comparisons were not possible for outcomes related to types of fracture reduction, open reduction, intraoperative fixation, and number of pins used.

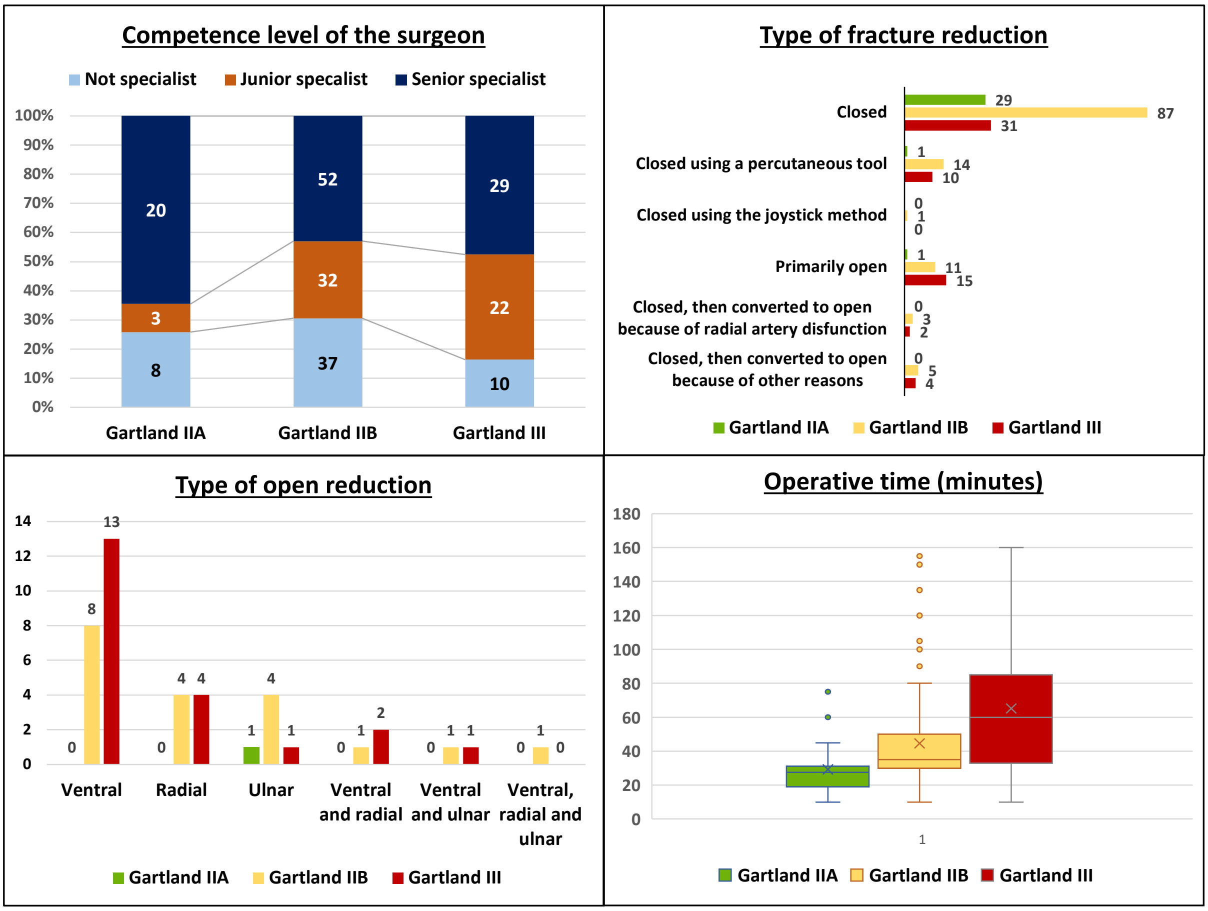

Figure 22. *Operative data by fracture type groups: a column chart comparing the competence level of the surgeon, a column chart comparing the type of fracture reduction, a column chart comparing the type of open reduction, and a box chart comparing the operative time in minutes. All comparisons are between Gartland IIA, Gartland IIB and Gartland III groups.*

4.2.2.3. Postoperative data summary

Postoperative fixation types were documented in all 217 cases: 168 patients received a dorsal cast with U-extension (elbow at 90 degrees) (77.42%), 46 were treated with a dorsal cast (elbow at 90 degrees) (21.2%), in two cases no orthotic device was applied (0.92%) (these two patients were treated with fixateur externe), and one patient was given an orthosis (0.46%).

Postoperative analgesic usage was reported in 211 cases, with 202 patients receiving some form of analgesics (95.73%), and nine not receiving any postoperative analgesics (4.27%). Painkillers prescribed for home use were documented in 204 cases; 139 patients received a prescription (68.14%), while 65 did not (31.86%).

Postoperative antibiotic usage was noted in 213 cases, with 200 patients not receiving antibiotics (93.9%), and 13 receiving them postoperatively (6.1%).

Regarding early complications, 191 out of 215 patients suffered none after surgery (88.48%), while 24 experienced some early complications (11.52%). Early complications included 20 neurological (9.3%), three vascular (1.4%), and two bone-related (0.93%) (Figure 23.).

Late complications were reported in 204 cases; 167 did not report any (81.86%), while 37 reported various late complications (18.14%), including 17 neurological (8.33%), one vascular (0.49%), six bone-related (2.94%), six superficial infections (2.94%), one deep infection (0.49%), and three wound healing problems (1.47%). Pins were removed early in eight cases due to protrusion (3.92%), five cases reported loss of movement in the elbow (2.45%), two instances of significant elbow swelling (0.98%), and one case of fever (0.49%). No cases of compartment syndrome were reported (Figure 23.).

No statistically significant differences were found when examining the effects of preoperative and postoperative antibiotic use ($p=0.5981$ and $p=0.7353$ respectively) and operative time ($p=0.2448$) on infection rates. All patients who developed an infection post-surgery (seven cases, six of which were superficial) had received preoperative antibiotics, and none received postoperative antibiotics. The operative time for these patients ranged from 20 to 45 minutes. No lasting complications due to infection were registered.

The only postoperative outcome that showed a significant difference was the weeks until pins were removed ($p=0.0125$), particularly between the Gartland IIA and Gartland IIB groups ($p=0.0053$) (Gartland IIA mean: 6.27, Gartland IIB mean: 5.0, Gartland III mean: 4.66). Dunn's post hoc test indicated that the difference between Gartland IIA and Gartland III was close to being significant ($p=0.0477$, though here $p<0.025$ was considered statistically significant) (Figure 23.).

There were no significant differences when comparing early complications ($p=0.0988$), prescribed painkillers for home use ($p=0.384$), and late complications ($p=0.6403$).

Due to the low sample size in various subgroups, statistical analysis was not feasible for outcomes including the type of postoperative fixation, analgesia and antibiotic use, as well as specific early vascular, neurological, and bone-related complications.

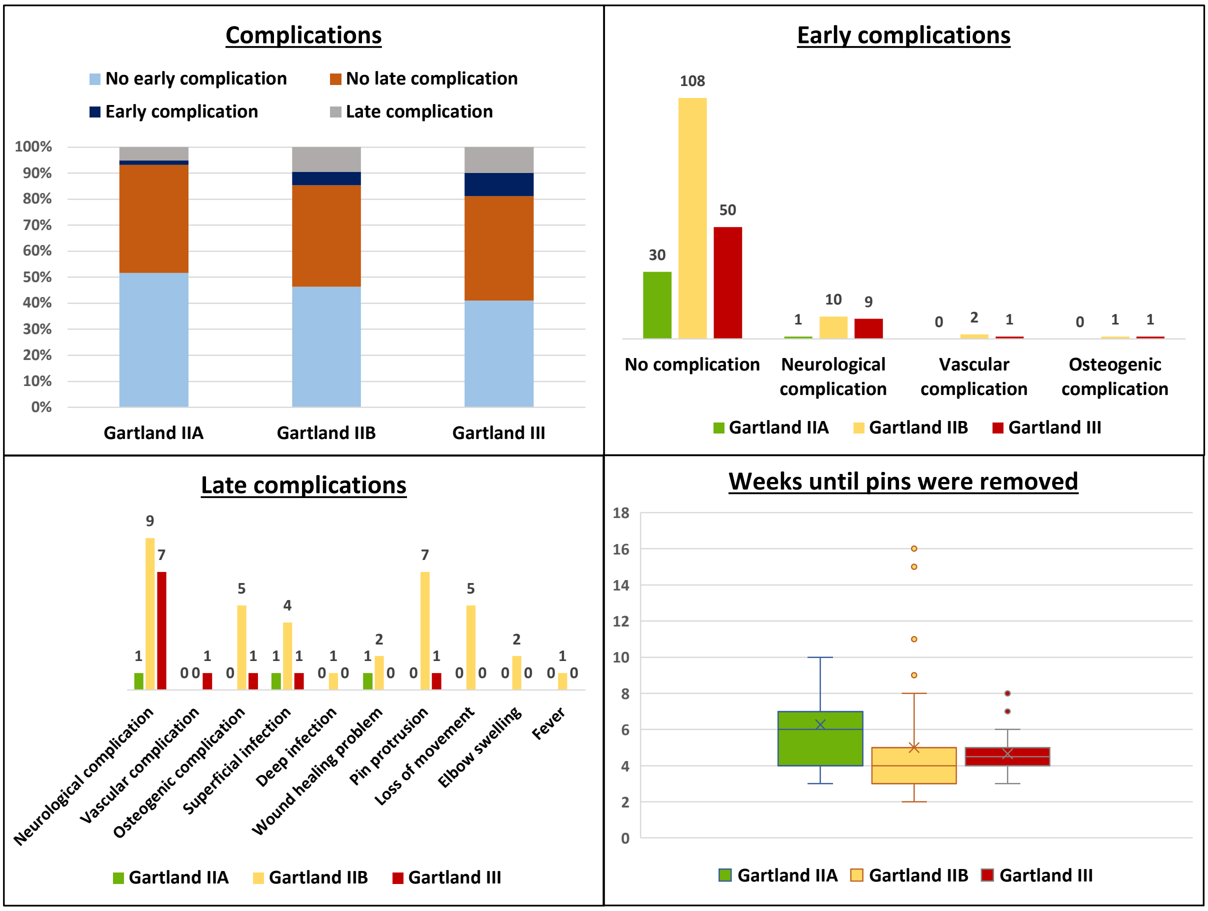

Figure 23. *Postoperative data by fracture type groups: a column chart comparing the early and late complication rates, a column chart comparing the early complication rates in detail, a column chart comparing the late complication rates in detail, and a box chart comparing the time passed until the pins were removed from the patients. All comparisons are between Gartland IIA, Gartland IIB and Gartland III groups.*

4.2.3. Discussion

Using data from a prospective multicentre registry, our study examined demographics and various preoperative, operative, and postoperative factors of paediatric SCHF patients, categorized by fracture types based on anteroposterior and lateral radiographs: Gartland type IIA, IIB, and III. We statistically analysed and compared these three groups.

Our main findings indicate that oxygen saturation at initial inspection was significantly lower in more severe fractures, the BMI did not significantly influence fracture type. No significant differences were found in early or late complications, and pins were retained longer in patients with the most benign fracture types.

Our study adds a crucial piece to the understanding of paediatric trauma care, promoting a dynamic, evidence-based approach that responds to the evolving landscape of medical knowledge and patient needs.

The average age in our study was 6.52 years, which is older than many studies [37, 42, 56, 149], but younger than others [39, 40].

We observed a sex difference in severity: more males in the Gartland IIA group and more females in the Gartland IIB group, with no significant sex difference in the Gartland III group. The overall female ratio was 53.46%. Some studies presented a male predominance [39, 41, 93, 150], while others reported the opposite [43], or little variance, similar to ours [37, 83, 151].

We found no significant association between BMI and fracture type, consistent with studies by Peña-Martínez V. et al. [152], and Mitchelson AJ. et al. [153], although Seeley MA. et al. [154] found correlations between higher BMI, more severe fractures, and more frequent complications, meanwhile, Suganuma S. et al. [155] identified high BMI as a significant contributor to malrotation.

Oxygen saturation at first inspection was slightly lower for more severe fractures, with significant statistical differences between Gartland II and III (Gartland IIA mean: 98.29%, IIB mean: 98.19%, III mean: 96.78%). While the difference may seem small, studies like Zhu T. et al. [156], where they compared well-perfused hands with poorly-perfused hands suggest that even minor differences in saturation could indicate vascular compromise in children. In the group with poor perfusion, oxygen saturation remained above 95% for all 76 patients. This suggests that even minor variations in oxygen saturation in children might indicate vascular compromise. Some studies have used pulse oximeters to monitor circulation by analysing waveforms, but did not focus on saturation levels [157, 158].

Operative times varied significantly, with more complex fractures requiring longer correction times. Obesity and open reduction were factors associated with longer operative times and high BMI with malrotation in the study by Suganuma S. et al. [155].

Due to low sample sizes in different subgroups, we were not able to statistically compare closed pinning to open reduction among the three groups. However, a trend towards more open reductions in complex fractures was evident.

Intraoperative local analgesic use did not vary significantly between groups, suggesting that analgesic administration is more dependent on the surgeon's preference and local practices than on fracture type.

A notable finding was that surgeons retained pins for the longest duration in the Gartland IIA group, averaging 6.27 weeks (43.89 days), whereas they removed pins the earliest in Gartland III patients, averaging 4.66 weeks (32.62 days). Zusman NL. et al. [159] reported pin removal at an average of 23.8 days post-surgery, curiously the same duration noted in Garg S. et al.'s study [160]. In contrast, Badin D. et al. [161] recorded an average removal time of 32 days. Our findings suggest that in our country, pins tend to be removed later in less severe fractures, possibly due to more frequent need for open reductions in severe fractures, giving surgeons greater confidence in the stability of the reduction and fixation achieved in the operating room, thus reducing the fear of redislocation. Less experienced surgeons might also leave pins in longer due to concerns over redislocation. Figure 22 shows that few Gartland III fractures were treated by non-specialists, while more senior specialists typically managed Gartland IIA fractures, with a higher proportion of non-specialist or junior specialist surgeons handling Gartland IIB fractures. This does not provide a definitive explanation for our findings, and further research could offer more clarity. Additionally, recording data in weeks could have slightly skewed the comparison.

We found no significant differences in early or late complications across fracture types, although there was a trend towards more complications in more severe fractures, primarily neurological deficits. Similar to LiBrizzi CL. et al. [151], who reported a 9.5% incidence of neurological injuries, our study found a 9.3% incidence. A meta-analysis by Babal JC. et al. [50] aggregated data from 5154 paediatric SCHFs with dislocation and identified neurapraxia in 11.3% of the patients. Other studies reported either fewer [43, 85] or more [162] cases of neurological deficits.

Overall, these results underscore the need for more detailed studies to explore the implications of surgical treatment options and outcomes for paediatric SCHF patients, considering the subtleties of each fracture type and the nuances of surgical practice.

4.2.4. Limitations

Our main limitation was that the data analysed were national, potentially limiting its applicability to other countries. Additionally, not all results were consistently reported across all cases, leading to some outcomes representing less than the entire cohort. Even with a large overall study size, the creation of many subgroups within the registry posed challenges for statistical analysis due to the small sample sizes in these subcategories. Although data were collected prospectively, there was no requirement for surgeons to conduct follow-ups at uniform times, complicating the analysis further. Moreover, the database lacks patient-reported outcome measures.

Our study is observational and not a prospective randomized trial, which restricts our ability to establish causal relationships between different interventions.

4.2.5. Conclusions

Our study underscores the importance of initial oxygen saturation levels as potential indicators of fracture severity. It also highlights the need for close monitoring of neurological complications and the extended duration of pin usage, underscoring the importance of tailored treatment approaches for paediatric SCHFs.

5. Publications and scientific metrics

5.1. First author publications

- **Vajda M**, Szakó L, Hegyi P, Erőss B, Görbe A, Molnár Zs, Kozma K, Józsa G, Bucsi L, Schandl K (2022) Tenodesis yields better functional results than tenotomy in long head of the biceps tendon operations - a systematic review and meta-analysis. Int Orthop 46:1037–1051. https://doi.org/10.1007/s00264-022-05338-9 (Q1, IF: 2.7)
- **Vajda M**, Lőrincz A, Szakó L, Szabó L, Kassai T, Zahár Á, Józsa G (2024) The first analysis of a multicentre paediatric supracondylar humerus fracture (SCHF) registry by fracture type. Arch Orthop Trauma Surg 145:39. https://doi.org/10.1007/s00402-024-05644-4 (Q1, IF: 2.0)

5.2. Co-author papers

- Leiner T, Nemeth D, Hegyi P, Ocskay K, Virág M, Kiss Sz, Rottler M, **Vajda M**, Váradi A, Molnár Zs (2022) Frailty and Emergency Surgery: Results of a Systematic Review and Meta-Analysis. Front Med (Lausanne) 9:811524. https://doi.org/10.3389/fmed.2022.811524 (Q1, IF: 3.9)

5.3. Metrics

- Number of publications related to the subject of the thesis: 2
  - Cumulative impact factor of publications related to the thesis: 4.7
  - Q1: 2, Q2: 0, Q3: 0, Q4: 0
- Number of total accepted articles: 3
  - Cumulative impact factor of the published articles: 8.6
  - Q1: 3, Q2: 0, Q3: 0, Q4: 0
- Number of citations according to MTM2 (as of 11.04.2025): 31
  - https://m2.mtmt.hu/gui2/?type=authors&mode=browse&sel=10098226&view=pubTable
- Number of total citations according to Google Scholar (as of 11.04.2025): 38
  - https://scholar.google.com/citations?hl=en&user=xmhzhokAAAAJ&view_op=list_works&gmla=AGd7smGL-hAIhJWKfF7Rz36DdKkSR1bMXOa_MqZZo39SAneMD5zocbGGctKg68OFqNHElHsnWhhb6oe3A13AzwG4zPxNWq2GLyOmpA

6. PhD work and future perspectives

During my PhD, I participated in Translational Medicine training at the University of Pécs, where I also taught Pathophysiology at the Institute of Translational Medicine, enhancing my educational abilities. Additionally, I enrolled patients in prospective registries and randomized clinical trials as part of my research activities.

In addition to the completed projects mentioned, I am actively involved in developing a rotator cuff registry. This initiative required us to extensively review existing registries and thoroughly understand the mechanics of registry creation and maintenance. We collaborated with a foreign group experienced in managing a similar, albeit short-term registry and consulted with Hungarian experts in shoulder surgery. We also collected essential insights from colleagues skilled in establishing various registries. Through this collaborative effort, we successfully designed the forms for our registry, which will enable us to gather data on rotator cuff surgeries, such as demographic data, risk factors, symptoms, level of pain, physical status, type of pathology, fine details about the surgery and intraoperative status, complications, postoperative status of the shoulder, different shoulder scores (Constant, ASES) and working status after rehabilitation.

Beside my PhD work, I am also actively participating in orthopaedic and traumatological work, having been a resident in this field since 2017.

My future plans involve implementing the registry described above, to enhance my scientific knowledge. As a translational medicine student, I believe that integrating the findings of modern scientific research into clinical practice is the most critical aspect of my work.

7. Funding

For the meta-analysis project, the funding was provided by an Economic Development and Innovation Operative Programme Grant (GINOP-2.3.4–15-2020–00010) and by a Human Resources Development Operational Programme Grant (EFOP-3.6.2–16-2017–00006, EFOP-3.6.1–16-2016–00004), both co-financed by the European Union (European Regional Development Fund) within the framework of the Széchenyi 2020 Program.

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I would like to thank the multidisciplinary staff of the Institute for Translational Medicine for their help in planning study protocols, managing data, conducting statistical analyses, and publishing papers. My work could not have succeeded without the expertise of trained statisticians.

I am also immensely grateful to the physicians, nurses, and PhD students at each national and international centre who enrolled hundreds of patients in the studies. Managing such a large volume of patient data would not be possible without the dedication of our data administrators, who also deserve special thanks.

I owe heartfelt gratitude to my amazing wife. While I wrestled with this project, she tirelessly wrestled with our two little sprites day and night. Her support kept our lives from spiralling into chaos, without which I would likely still be buried in my notes.

9. References

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10. Appendix

10.1. Figures and tables

Figure 1. *Tendons and ligaments of the shoulder.*

Figure 2. *Elbow joint, showing ligaments.*

Figure 3. *Radiographs representing the Gartland classification.*

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Figure 19. *A Forest plot that compares the operative time of tenotomy and tenodesis. The black diamonds represent the effect of individual studies, and the vertical lines show the*

corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.

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Figure 23. *Postoperative data by fracture type groups: a column chart comparing the early and late complication rates, a column chart comparing the early complication rates in detail, a column chart comparing the late complication rates in detail, and a box chart comparing the time passed until the pins were removed from the patients. On the box plots the numbers show the median value of the specific outcomes. All comparisons are between Gartland IIA, Gartland IIB and Gartland III groups.*

Supplementary Table 1. *Characteristics of included studies (Comparing the results of tenotomy and tenodesis in LHBT surgeries)*

First author, year	Study design	Country	Age (mean)	Sex (female % of total)	Number of patients	Follow-up time in months	Inclusion criteria	Type of TT	Type of TD
Belay et al., 2019 [135]	randomized, controlled, patient-blinded, single-center	UK	TT: 57.7 TD: 52.9	TT: 5 TD: 14.3	TT: 20 TD: 14	TT: 24 TD: 24	LHBT pathology confirmed with imaging and physical examination (RCRs not excluded, but also not necessary)	ASC scissors: LHBT cut from superior labrum	ASC, interference screws
Castricini et al., 2018 [136]	randomized, controlled, assessor-blinded, single-center	Italy	TT: 59.9 TD: 57.1	TT: 54.8 TD: 70.8	TT: 31 TD: 24	TT: 24 TD: 24	grade I or II full-thickness reparable supraspinatus tendon tear with a LHBT lesion, patients over 40 years old	ASC, releasing of the LHBT from its insertion on the superior glenoid labrum with electrocautery	ASC, interference screws
De Carli et al., 2012 [144]	randomized, controlled, single-center	Italy	TT: 59.6 TD: 56.3	TT and TD reported together: 26	TT: 30 TD: 35	TT: 23 * TD: 25 *	small to large rotator cuff tear and the presence of an associated degenerative lesion of the LHBT, patients younger than 65	ASC, scissors were used to sever the tendon at its junction with the superior labrum.	ASC, suturing the LHB to cuff tendons
García-Rellan et al., 2020 [137]	randomized, controlled, multi-center	Spain	TT: 54.7 TD: 50.73	TT: 0 TD: 0	TT: 23 TD: 18	TT: 12 TD: 12	diagnosis of LHBT pathology in men between 40 and 65 years of age, (RCRs not excluded, but also not necessary)	ASC, sectioning the LHBT near of its insertion with an electrocoagulator	ASC, interference screws
Hufeland et al., 2019 [138]	randomized, controlled, examiner-blinded, single-center	Germany	TT: 52.8 TD: 51.5	TT: 63.64 TD: 22.22	TT: 11 TD: 9	TT: 12 TD: 12	isolated SLAP lesion type II–IV, 40–70 years of age (full thickness rotator cuff tear excluded)	ASC, transecting the tendon directly at the SLAP complex with an angulated punch	ASC, interference screws
Lee et al., 2016 [143]	randomized, controlled, double-blinded, single-center	Republic of Korea	TT: 62.8 TD: 62.9	TT: 80.357 TD: 75	TT: 56 TD: 72	TT: 25.1 # TD: 19.7 #	symptomatic LHBT partial tear and small - to medium-sized rotator cuff tears that required surgical repair, after at least one month of unsuccessful conservative therapy	ASC, funnel-shaped tenotomy: dividing the LHBT at its proximal origin of the labrum	ASC, interference screws
MacDonald et al., 2020 [139]	randomized, controlled, double-blinded, multi-center	Canada	TT: 56.3 TD: 58.7	TT: 21.05 TD: 17.54	TT: 57 TD: 54	TT: 24 TD: 24	patients over 18 years old with intraoperative confirmation of a lesion of the LHBT (RCRs not excluded, but also not necessary)	ASC, LHBT was detached from its proximal anchor to the superior labrum	ASC, interference screws (n=37), open subpectoral approach with a button (n=17)
Mardani et al., 2018 [140]	randomized, controlled, single-center	Iran	TT: 54.5 TD: 55.5	TT: 31 TD: 33.3	TT: 29 TD: 33	TT: 24 TD: 24	patients aged 45 to 60 years, arthroscopic RCR with positive biceps test before surgery, and intraoperatively confirmed LHBT pathology	ASC, with the use of a forceps	ASC, reabsorbable interference screw
Oh et al., 2016 [141]	randomized, controlled, examiner-blinded, single-center	Republic of Korea	TT: 61.04 TD: 56.61	TT: 66.67 TD: 32.26	TT: 27 TD: 31	TT: 21.98 TD: 21.46	rotator cuff tear in addition to an intraoperatively confirmed SLBC lesion (type II SLAP lesion, partial tear of LHBT, partial biceps pulley tear)	ASC, scissors at the junction between the biceps tendon and superior labrum	ASC, suture anchor
Zhang et al., 2015 [142]	randomized, controlled, examiner-blinded, single-center	China	TT: 61* TD: 61*	TT: 54.25 TD: 52.7	TT: 77 TD: 74	TT: 25 * TD: 25 *	patients affected by both rotator cuff tears and LHBT pathologies, age: older than 55	ASC, the tendon was debrided and cut as close as possible to the labrum	ASC, suture anchor
Zhang et al., 2019 [134]	randomized, controlled, single-center	China	TT: 62.2 TD: 60.5	TT: 66.67 TD:63.64	TT: 18 TD: 22	TT and TD reported together: 14.3 #	confirmed LHBT pathology, at least six months of unsuccessful conservative therapy, age: between 50 and80 years (RCRs were excluded)	ASC, cut the LHBT at the superior labrum	ASC, suture anchor

*: median, #: mean, TT: tenotomy, TD: tenodesis, LHBT: long head of the biceps tendon, RCR: rotator cuff repair, ASC: arthroscopy, LHBT pathology included: degenerative tear, partial rupture, subluxation, dislocation, tenosynovitis, hypertrophy, superior labral tear from anterior to posterior (SLAP) lesions, partial biceps pulley tear

Supplementary Table 2. *Systematic review: Comparing the final data of the individual articles (TT vs TD in LHBT surgeries)*

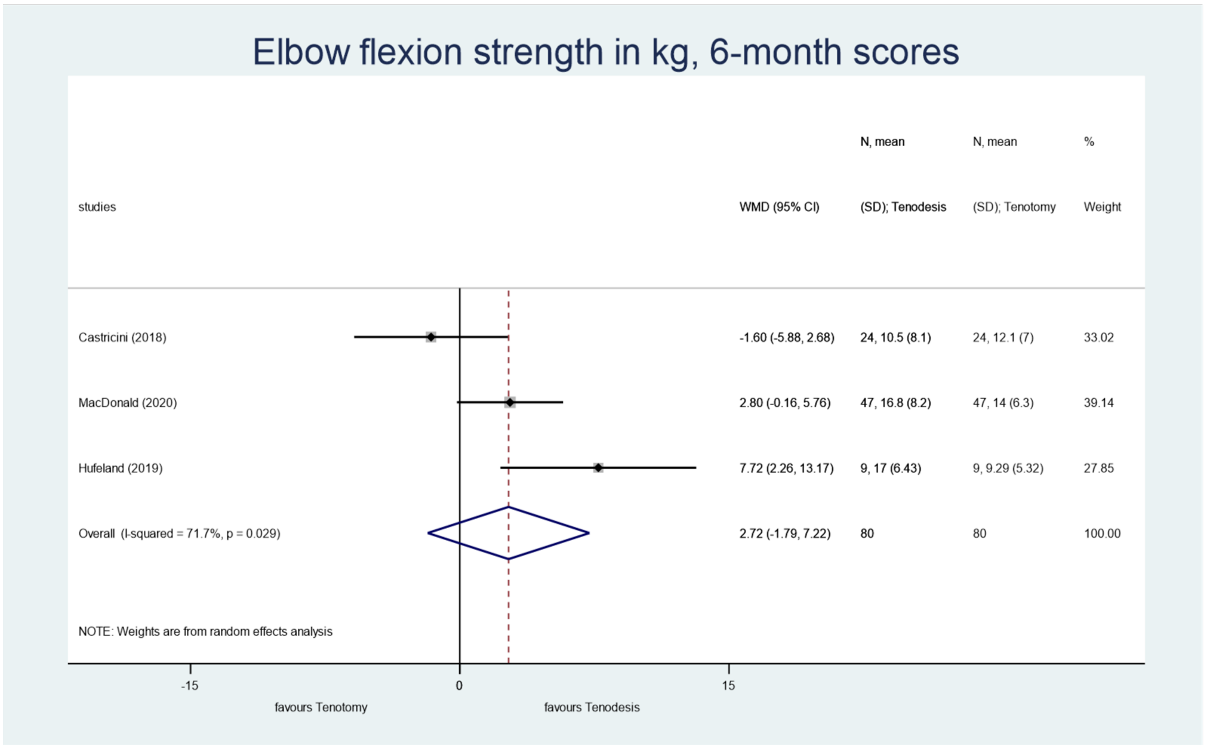
	Elbow flexion strength in kg (TT/TD)	Elbow flexion strength in SI (TT/TD)	Forearm supination strength in SI (TT/TD)	Constant score (TT/TD)	ASES score (TT/TD)	SST score (TT/TD)	Pain on VAS (TD/TT)	Number of reported bicipital cramping pain events (TD/TT)	Number of reported bicipital groove pain events (TD/TT)	Number of reported Popeye deformity events (TD/TT)
measure of effect	WMD (95%CI)	WMD (95%CI)	WMD (95%CI)	WMD (95%CI)	WMD (95%CI)	WMD (95%CI)	WMD (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Belay (2019) [135]	n.a.	n.a.	n.a.	n.a.	-8.22 (-22.09, 5.65)	n.a.	-0.82 (-2.25, 0.61)	n.a.	1.21 (0.27, 5.40)	0.23 (0.02, 2.24)
Castricini (2017) [136]	-3.50 (-7.52, 0.52)	n.a.	n.a.	-0.8 (-4.66, 3.06)	n.a.	n.a.	0.00 (-1.04, 1.04)	1.00 (0.02, 53.90)	n.a.	0.19 (0.06, 0.64)
De Carli (2012) [144]	-0.10 (-1.48, 1.28)	0.03 (-0.73, 0.79)	n.a.	2.6 (0.21, 4.99)	n.a.	1.1 (0.47, 1.73)	n.a.	n.a.	n.a.	0.07 (0.00, 0.52)
García-Rellan (2020) [137]	2.74 (-0.92, 6.40)	n.a.	n.a.	0.80 (-1.29, 2.89)	n.a.	n.a.	1.02 (0.41, 1.63)	1.71 (0.33, 8.94)	1.73 (0.39, 7.72)	0.10 (0.02, 0.52)
Hufeland (2019) [138]	7.61 (2.55, 12.66)	0.09 (-0.74, 0.92)	0.13 (-0.69, 0.95)	10.07 (2.18, 19.22)	18.3 (4.38, 32.22)	1.20 (-0.29, 2.69)	n.a.	1.00 (0.02, 56.40)	n.a.	0.33 (0.03, 3.93)
Lee (2016) [143]	n.a.	-0.01 (-0.03, 0.01)	0.18 (0.15, 0.21)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.24 (0.07, 0.80)
MacDonald (2020) [139]	-1.00 (-3.76, 1.76)	n.a.	n.a.	n.a.	-2.90 (-10.57, 4.77)	n.a.	-0.60 (-1.76, 0.56)	n.a.	n.a.	0.22 (0.07, 0.74)
Mardani (2018) [140]	n.a.	n.a.	n.a.	1.84 (-0.41, 4.09)	n.a.	0.28 (-0.12, 0.68)	0.01 (-0.04, 0.07)	0.03 (0.00, 0.57)	n.a.	0.10 (0.01, 0.86)
Oh (2016) [141]	n.a.	0.06 (-0.16, 0.29)	0.24 (0.01, 0.47)	n.a.	1.44 (-2.85, 5.73)	n.a.	-0.09 (-0.57, 0.39)	0.87 (0.05, 14.56)	1.13 (0.37, 3.46)	0.59 (0.19, 1.81)
Zhang (2015) [142]	n.a.	0.00 (-0.06, 0-06)	0.00 (-0.05, 0.05)	0.90 (0.01, 1.79)	n.a.	n.a.	0.10 (-0.34, 0.54)	1.00 (0.02, 51.09)	n.a.	0.28 (0.06, 1.38)
Zhang (2019) [134]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-0.13 (-0.44, 0.18)	n.a.	n.a.	0.03 (0.00, 0.52)

TT: tenotomy, TD: tenodesis, LHBT: long head of the biceps tendon ASES: American Shoulder and Elbow Surgeons, SST: Simple Shoulder Test, VAS: Visual Analog Scale, SI: Strength Index, kg: kilogram, OR: Odds Ratio, WMD: Weighted Mean Difference, n.a.: not available

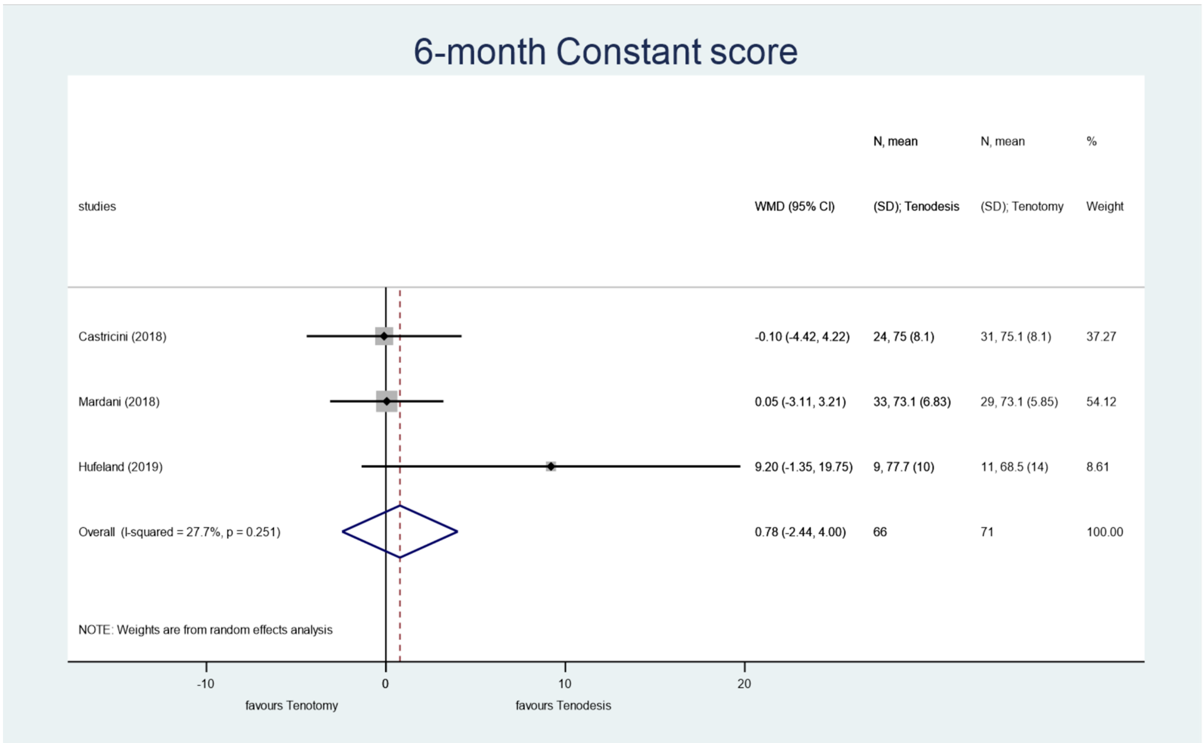
Supplementary Table 3. *Summary of the certainty of evidence according to the GRADE analysis (TT vs TD in LHBT surgeries)*

	Certainty assessment						**№ of patients**		**Effect**		**Certainty**	**Importance**
Outcome	**№ of studies**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	**tenotomy**	**tenodesis**	**Relative (95% CI)**	**Absolute (95% CI)**		
Elbow flexion strength in kg, 6-month scores	3	not serious	serious [a]	not serious	serious [b]	none	80	80	-	WMD: 2.82 (-1.79 to 7.22)	⊕⊕◯◯ LOW	IMPORTANT
Elbow flexion strength in kg, 12-month scores	3	not serious	not serious	serious [c]	not serious	none	80	74	-	WMD: 3.67 (1.07 to 6.27)	⊕⊕⊕◯ MODERATE	IMPORTANT
Supination strength in kg, 12-month scores	3	not serious	not serious	serious [c]	serious [b]	none	80	69	-	WMD: 0.36 (0.08 to 0.64)	⊕⊕◯◯ LOW	IMPORTANT
Constant score, 6-month scores	3	not serious	not serious	not serious	serious [d]	none	71	66	-	WMD: 0.78 (-2.44 to 4.00)	⊕⊕⊕◯ MODERATE	IMPORTANT
Constant score, 12-month scores	3	not serious	not serious	serious [c]	serious [b]	none	63	60	-	WMD: 2.26 (-1.12 to 5.65)	⊕⊕◯◯ LOW	IMPORTANT
Pain on VAS, 3-month scores	3	not serious	not serious	not serious	not serious	none	84	84	-	WMD: 0.99 (0.51 to 1.48)	⊕⊕⊕⊕ HIGH	IMPORTANT
Pain on VAS, 6-month scores	4	not serious	not serious	not serious	serious [d]	none	124	126	-	WMD: 0.05 (-0.21 to 0.30)	⊕⊕⊕◯ MODERATE	IMPORTANT
Pain on VAS, 12-month scores	4	not serious	serious [e]	serious [c]	serious [b]	none	116	115	-	WMD: 0.19 (-0.26 to 0.63)	⊕◯◯◯ VERY LOW	IMPORTANT
Pain on VAS, 24-month scores	4	not serious	not serious	not serious	serious [d]	none	132	119	-	WMD: 0.01 (-0.04 to 0.07)	⊕⊕⊕◯ MODERATE	IMPORTANT
6-month bicipital cramping pain events	3	not serious	not serious	not serious	serious [d]	none	4/69 (5.8%)	4/64 (6.3%)	OR: 0.92 (0.09 to 9.07)	5 fewer per 1 000 (from 57 fewer to 314 more)	⊕⊕⊕◯ MODERATE	IMPORTANT
24-month Popeye deformity events	3	serious [f]	not serious	not serious	not serious	none	40/105 (38.1%)	10/97 (10.3%)	OR: 0.19 (0.08 to 0.41)	82 fewer per 1 000 (from 94 fewer to 58 fewer)	⊕⊕⊕◯ MODERATE	IMPORTANT
Operative time	3	serious [f]	serious [g]	not serious	serious [h]	none	152	150	-	WMD: 17.15 (-2.05 to 36.35)	⊕◯◯◯ VERY LOW	NOT IMPORTANT

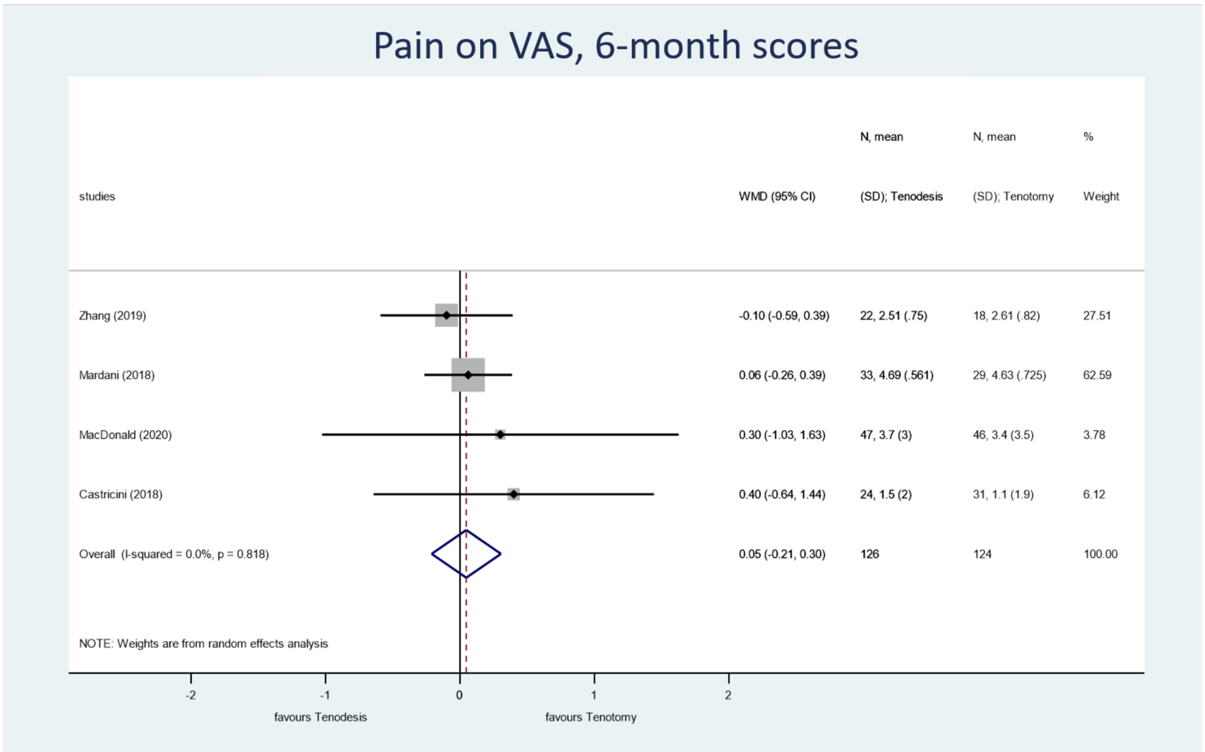
CI: Confidence Interval; OR: Odds Ratio, WMD: Weighted Mean Difference, kg: kilogram, VAS: Visual Analog Scale, **a:** Significant heterogeneity was detected (I^2 test: 71.7%, p=0.029), **b:** According to our Trial Sequential Analysis more clinical trials are needed, **c:** One of the studies only include men, **d:** Small sample size, wide CI, **e:** Significant heterogeneity was detected (I^2 test: 80.1%, p=0.002), **f:** According to our Risk of Bias assessment, one of the studies carries high risk of bias, **g:** Significant heterogeneity was detected (I^2 test: 97.5%, p<0.001), **h:** According to our Trial Sequential Analysis, the analysis of this outcome was inconclusive as there was potential spurious significance ($p < 0.05$)



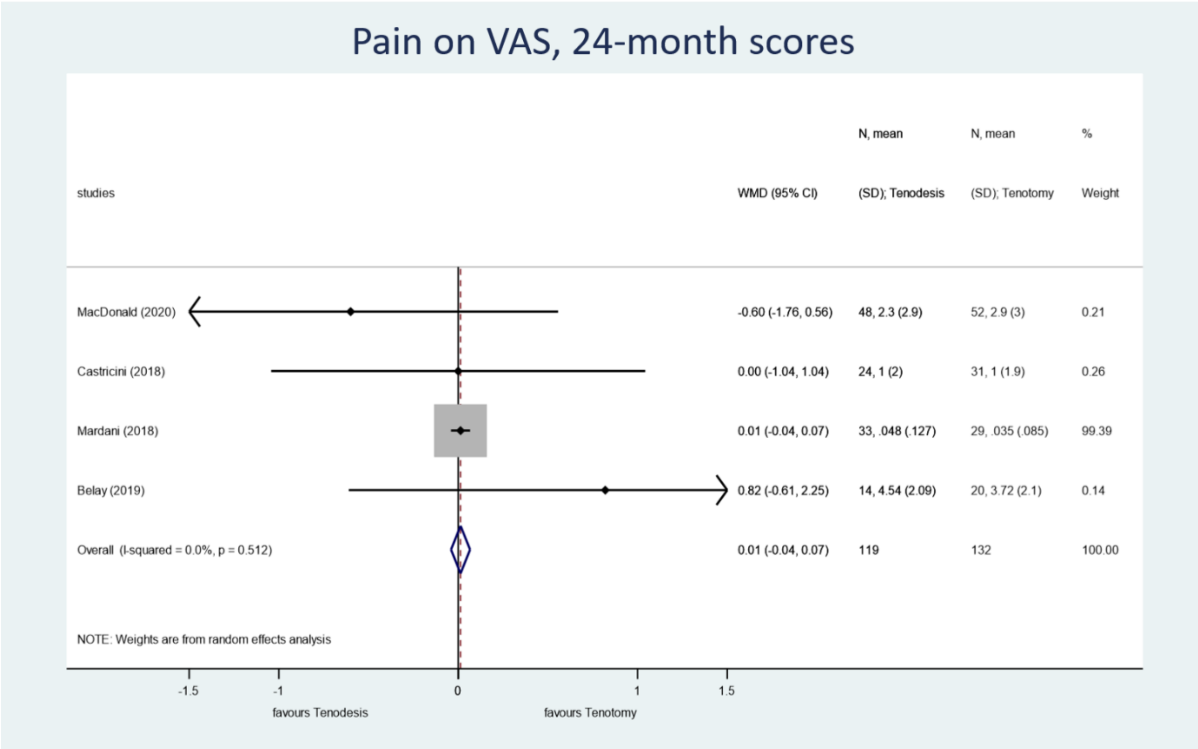
Supplementary Figure 1. *A Forest plot that compares the results of elbow flexion strength measurements in kilogram (kg) in tenotomy and tenodesis 6 months postoperatively. The black diamonds represent the effect of individual studies, and the vertical lines show the corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.*



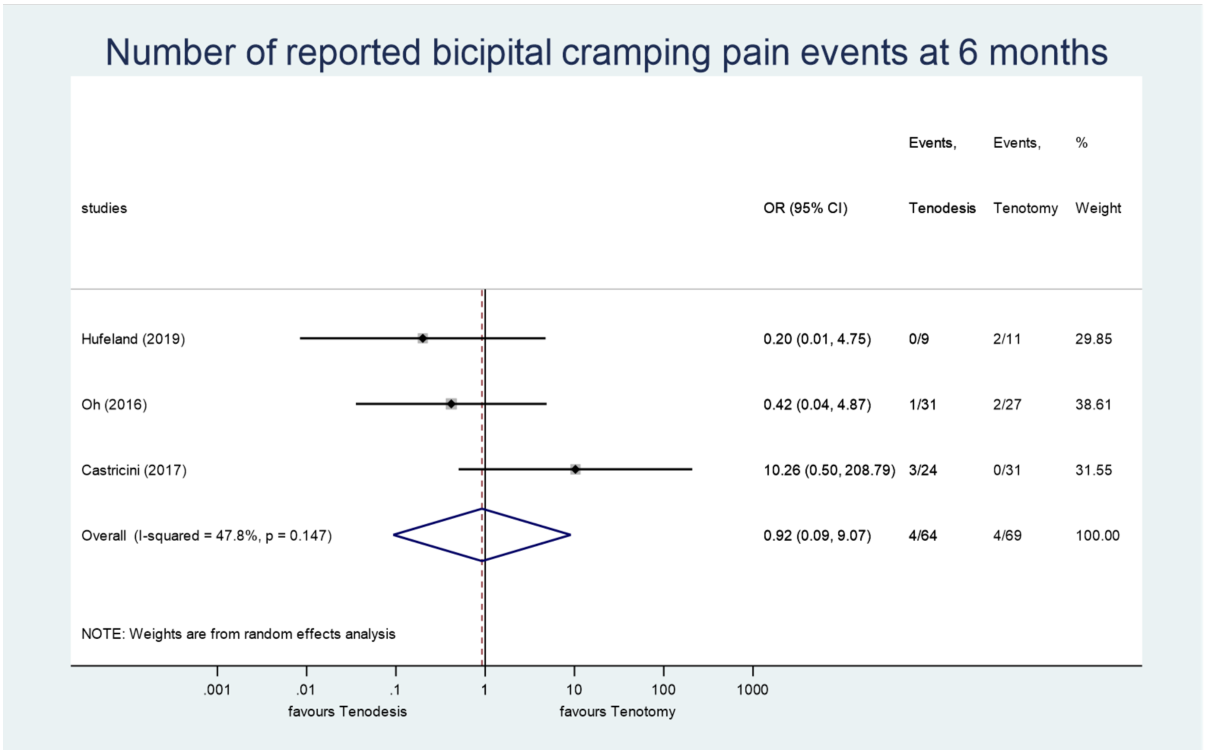
Supplementary Figure 2. *A Forest plot that compares the 6-month Constant scores of tenotomy and tenodesis. The black diamonds represent the effect of individual studies, and the vertical lines show the corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.*



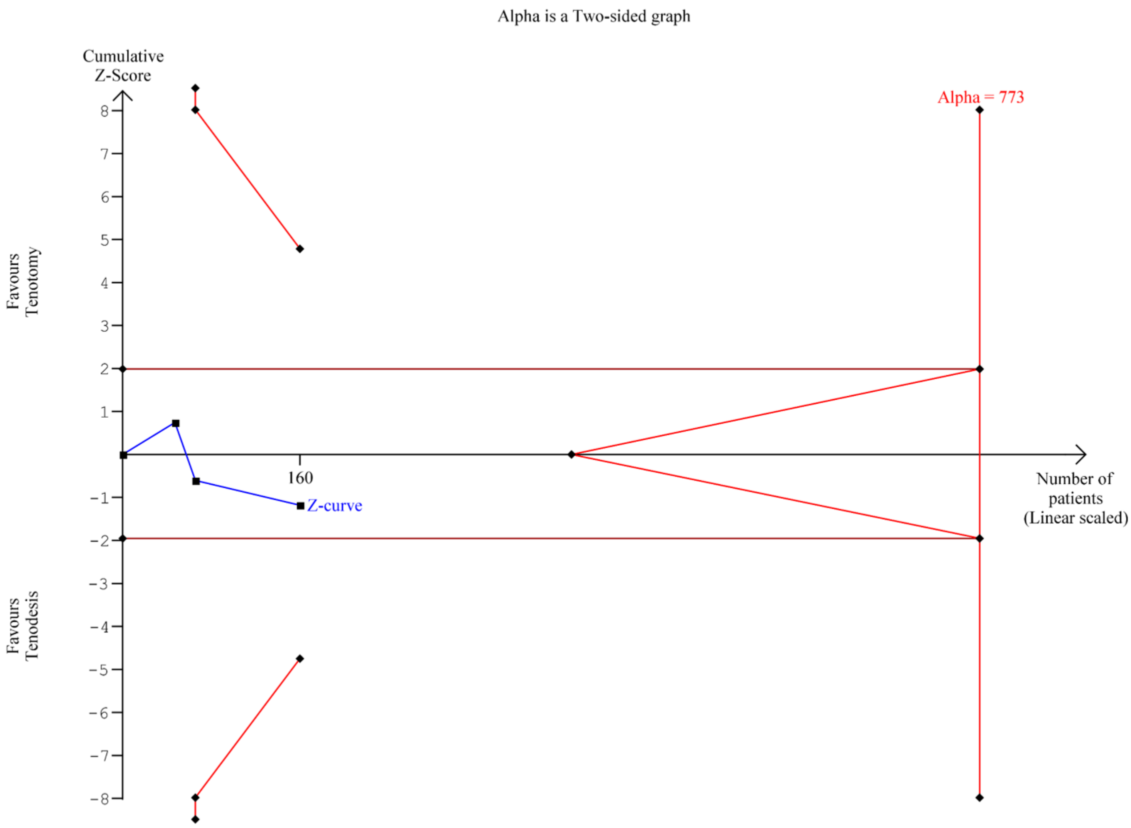
Supplementary Figure 3. *A Forest plot that compares the level of pain on the Visual Analog Scale (VAS) of tenotomy and tenodesis at the 6-month follow-up. The black diamonds represent the effect of individual studies, and the vertical lines show the corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.*



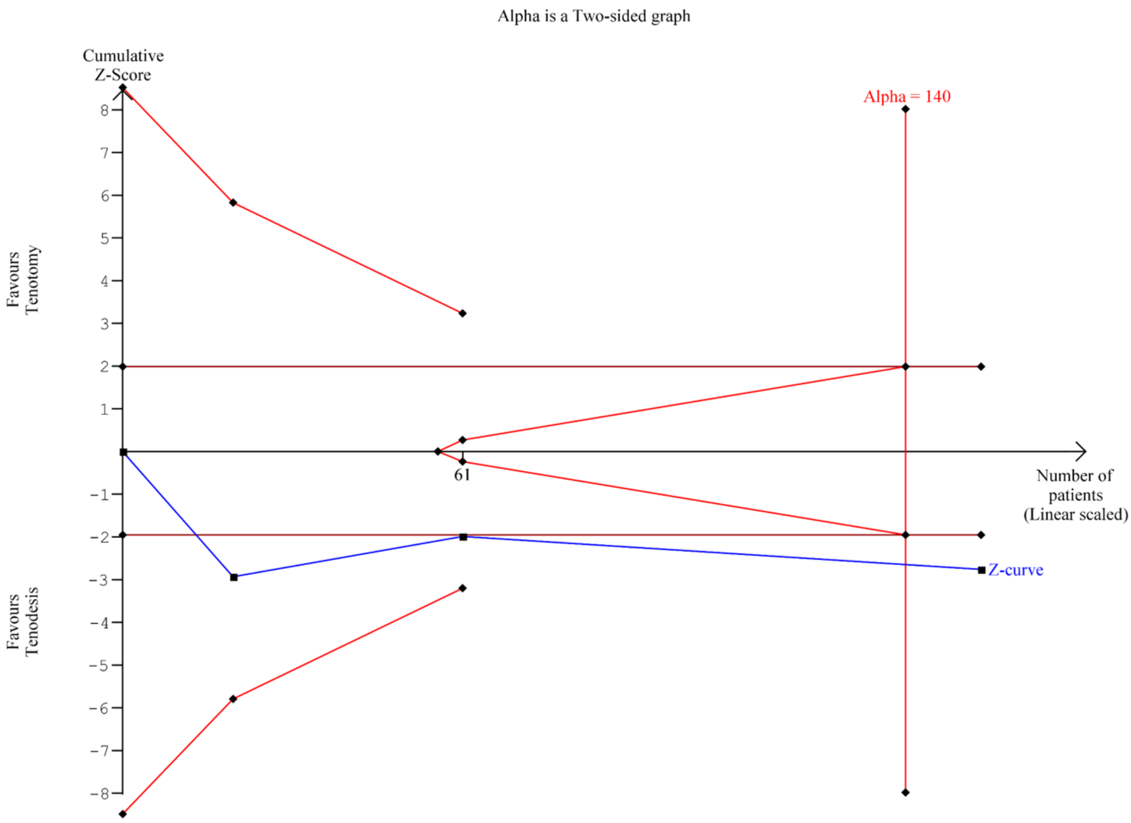
Supplementary Figure 4. *A Forest plot that compares the level of pain on the Visual Analog Scale (VAS) of tenotomy and tenodesis at the 24-month follow-up. The black diamonds represent the effect of individual studies, and the vertical lines show the corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.*



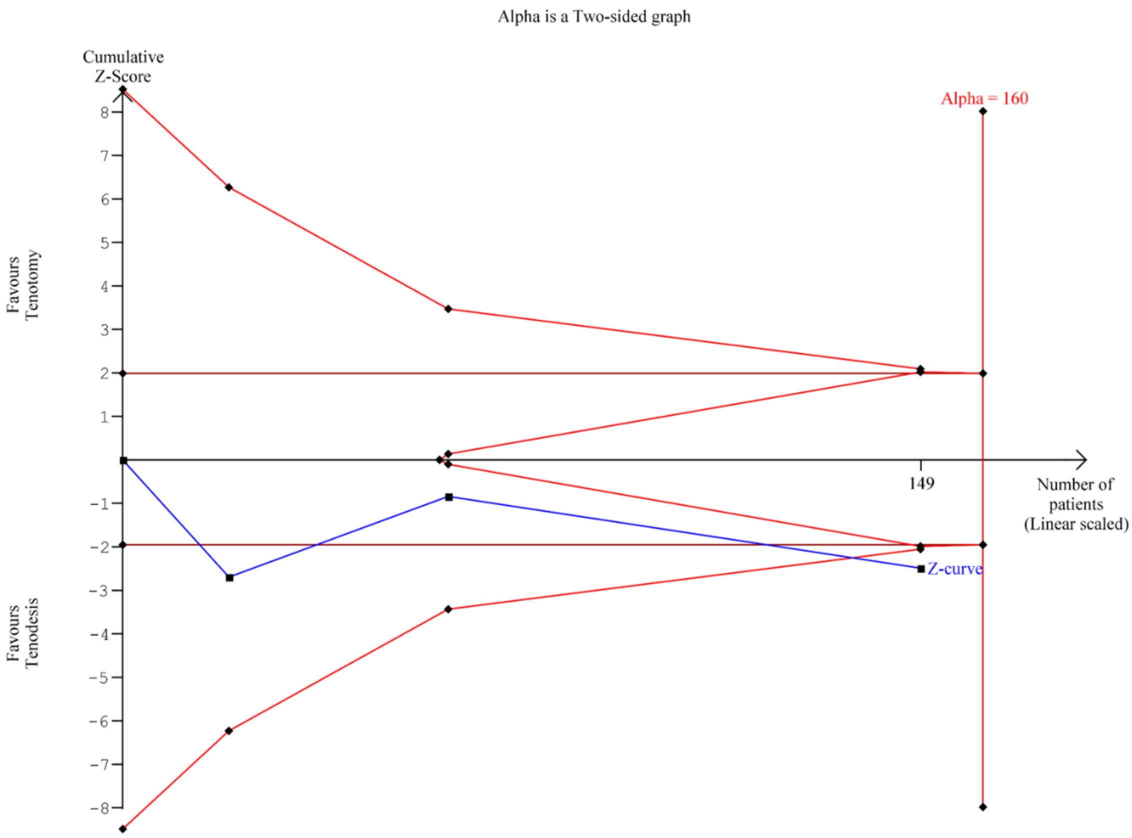
Supplementary Figure 5. *A Forest plot that compares the number of bicipital cramping pain events of tenotomy and tenodesis, 6 months postoperatively. The black diamonds represent the effect of individual studies, and the vertical lines show the corresponding 95% confidence intervals (CI). The size of the grey squares reflects the weight of a particular study. The blue diamond reflects the overall or summary effect. The outer edges of the diamonds represent the CIs.*



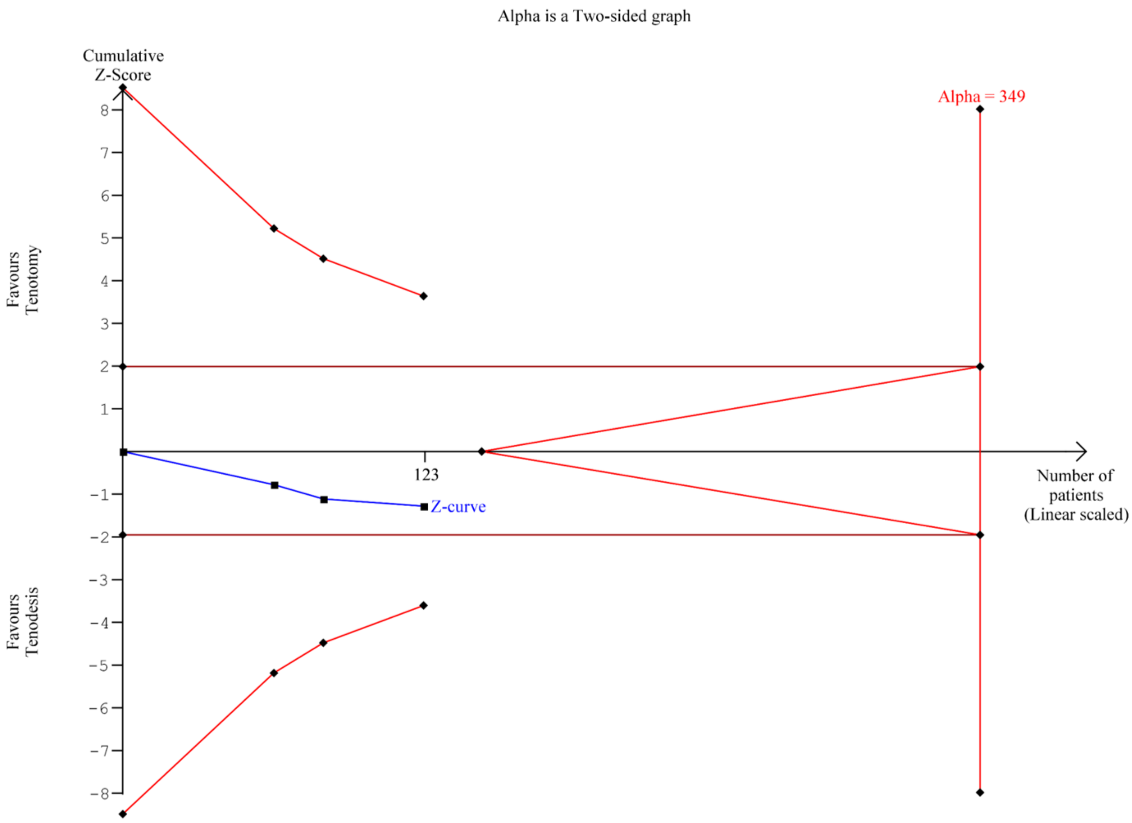
Supplementary Figure 6. *Trial sequential analysis (TSA) analysis for the 6-month elbow flexion strength in kg outcome. The Z curve represents the studies of the meta-analysis in chronological order. As the Z curve didn't cross any boundaries including the Alpha line, this outcome of the meta-analysis is inconclusive. More clinical trials are needed.*



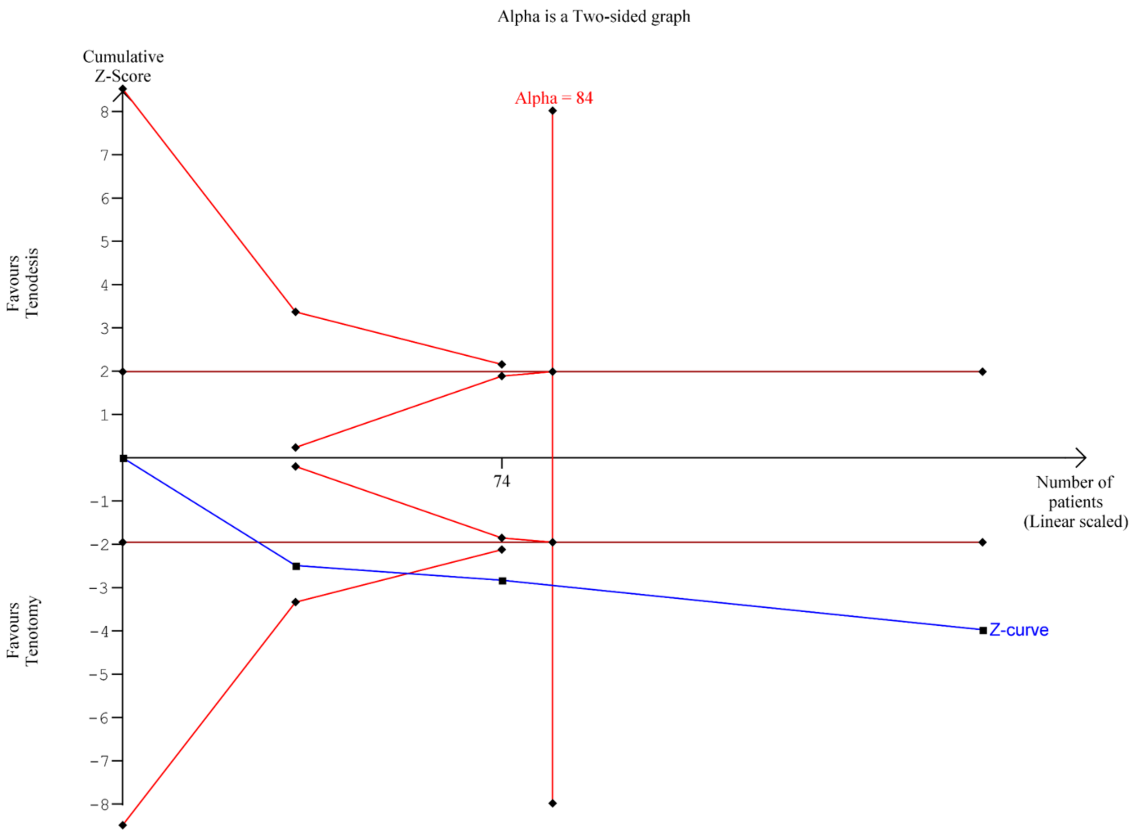
Supplementary Figure 7. *Trial sequential analysis (TSA) analysis for the 12-month elbow flexion strength in kg outcome. The Z curve represents the studies of the meta-analysis in chronological order. After the first study, the Z curve crossed the Conventional boundary, therefore the analysis was significant. However, the Z curve didn't cross the Trial Sequential boundary, the analysis is therefore potentially spurious. The Z curve reached and crossed the Alpha line; thus, the sample size exceeded the required meta-analysis sample size. This meta-analysis was inconclusive as there was potential spurious significance ($p < 0.05$). Since the required sample size was reached, further clinical trials are not required. Considering the raw data and comparing the TSA results to the forest plot, it is possible that some kind of bias may influence these results.*



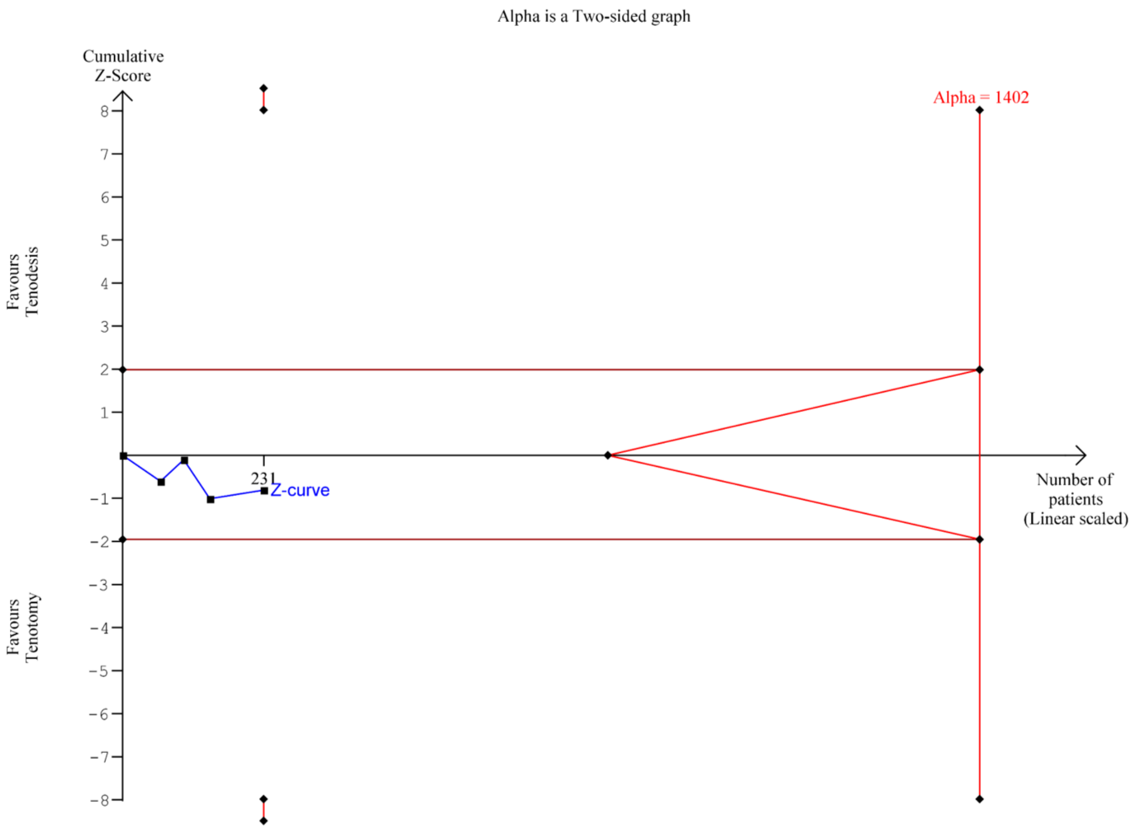
Supplementary Figure 8. *Trial sequential analysis (TSA) analysis for the 12-month forearm supination strength in kg outcome. The Z curve represents the studies of the meta-analysis in chronological order. After the first study, the Z curve crossed the Conventional boundary. After the third study, the Z curve crossed the Trial Sequential boundary too, depicting that the analysis was truly significant from that point. The sample size did not exceed the required meta-analysis sample size (Alpha). This meta-analysis was inconclusive. More clinical trials are needed to confirm the significance.*



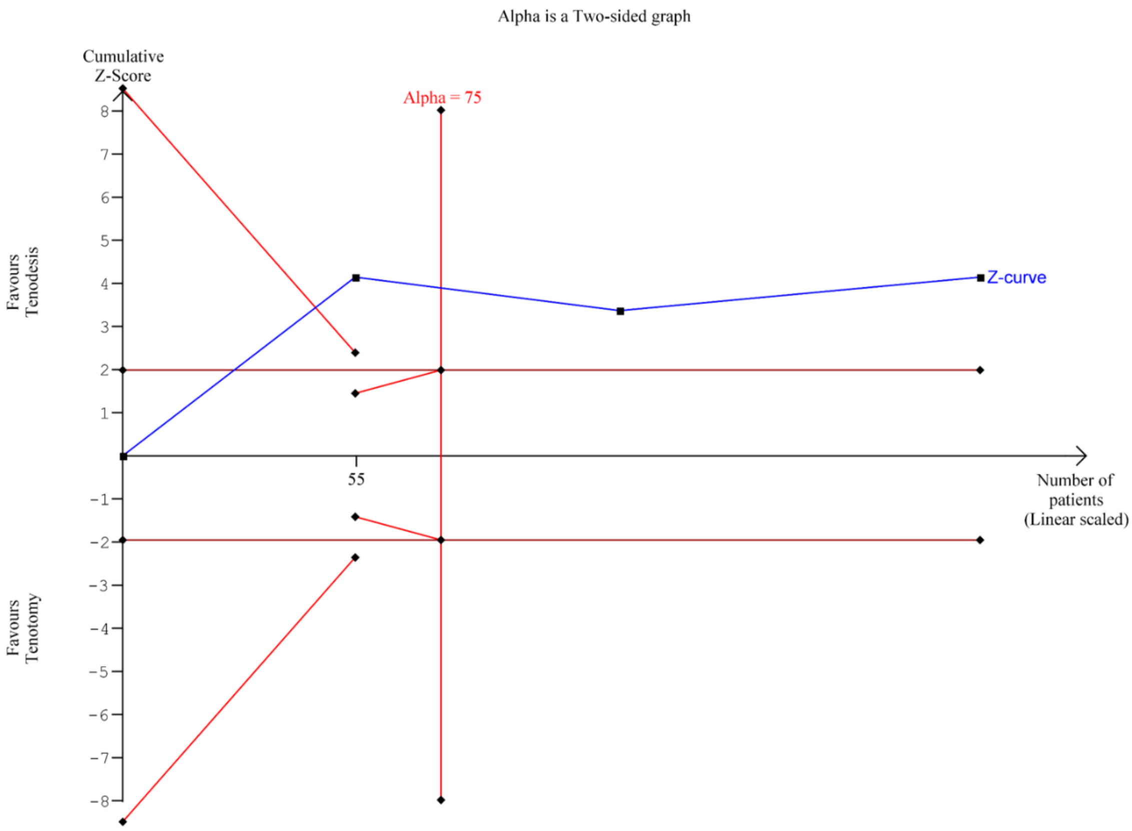
Supplementary Figure 9. *Trial sequential analysis (TSA) analysis for the 12-month Constant score outcome. The Z curve represents the studies of the meta-analysis in chronological order. As the Z curve didn't cross any boundaries including the Alpha line, this outcome of the meta-analysis is inconclusive. More clinical trials are needed.*



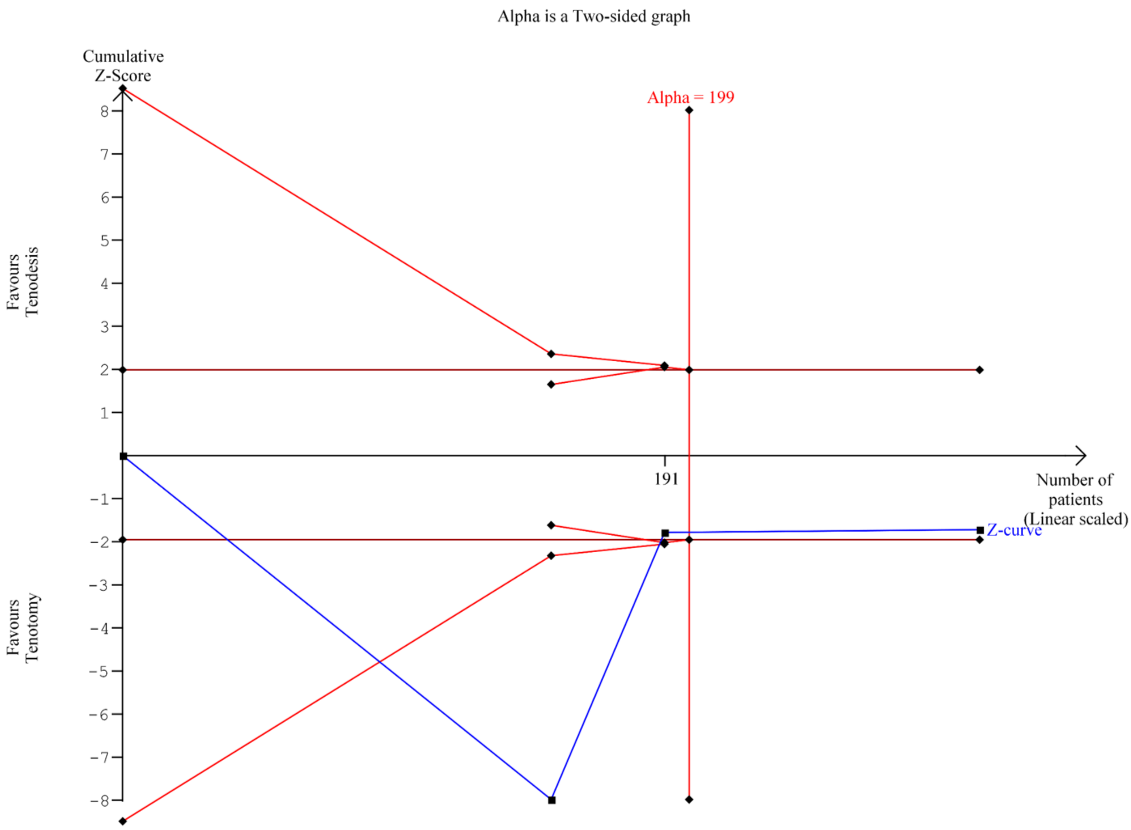
Supplementary Figure 10. *Trial sequential analysis (TSA) analysis for the 3-month pain levels on the Visual Analog Scale (VAS) outcome. The Z curve represents the studies of the meta-analysis in chronological order. After the first study, the Z curve crossed the Conventional boundary, therefore the analysis was significant. After the second study, the Z curve crossed the Trial sequential boundary showing real significance. The Z curve also reached and crossed the line of the Alpha after the second study. This means that the required sample size was reached after the second study. The tenotomy method was superior to the tenodesis method. Further clinical trials are not required.*



Supplementary Figure 11. *Trial sequential analysis (TSA) analysis for the 12-month pain levels on the Visual Analog Scale (VAS) outcome. The Z curve represents the studies of the meta-analysis in chronological order. As the Z curve didn't cross any boundaries including the Alpha line, the outcome of the meta-analysis is inconclusive. More clinical trials are needed.*



Supplementary Figure 12. *Trial sequential analysis (TSA) analysis for the occurrence of Popeye deformity at the 24-month follow-up outcome. The Z curve represents the studies of the meta-analysis in chronological order. After the first study, the Z curve crossed the Conventional boundary, the Trial Sequential boundary and also the Alpha line, therefore the analysis was truly significant from that point and reached the required sample size. The tenodesis method was superior to the tenotomy treatment. Further clinical trials are not required.*

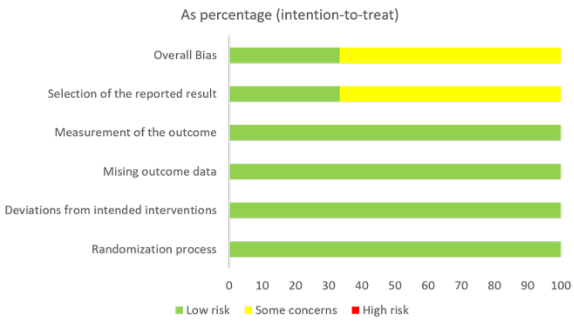


Supplementary Figure 13. *Trial sequential analysis (TSA) analysis for the operative time in minutes outcome. The Z curve represents the studies of the meta-analysis in chronological order. After the first study, the Z curve crossed the Conventional boundary as well as the Trial Sequential boundary, therefore the analysis was potentially significant. However, after the second study, the Z curve crossed the Alpha line as well as the Futility boundary. This means that the sample size exceeded the required meta-analysis sample size (when Z curve crossed the Alpha line). However, it also means that the significance of the meta-analysis was more spurious than reliable, as the Z curve crossed the Futility boundary. Therefore, this outcome of the meta-analysis was inconclusive, since there was potential spurious significance ($p < 0.05$). As the required sample size was reached, further clinical trials are not required. Considering the raw data and comparing the TSA results to the forest plot, it is possible that some form of bias may have caused these results.*

Elbow flexion strength in kg at 6-month

First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.

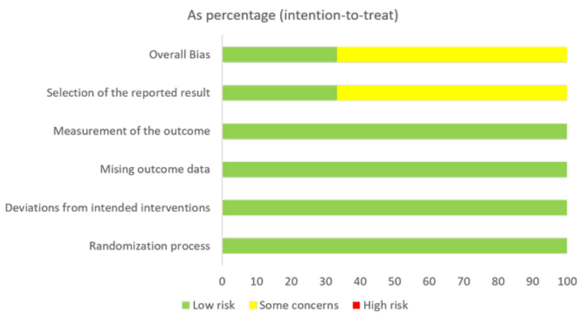


Supplementary Figure 14. *Risk of bias assessment of the 6-month elbow flexion strength outcome, measured in kilogram (kg).*

Elbow flexion strength in kg at 12-month

First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.

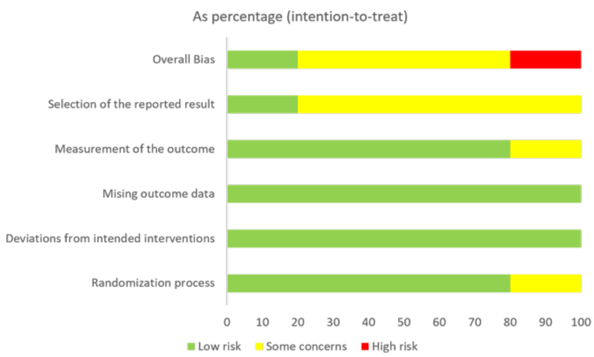


Supplementary Figure 15. *Risk of bias assessment of the 12-month elbow flexion strength outcome, measured in kilogram (kg).*

Elbow flexion strength in kg, final data

First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
DeCarli 2012	!	+	+	!	!	-
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.

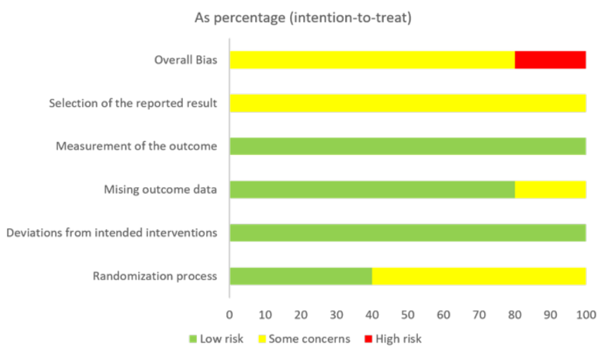


Supplementary Figure 16. *Risk of bias assessment of the final elbow flexion strength outcome, measured in kilogram (kg).*

Elbow flexion strength in SI, final data

First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
DeCarli 2012	!	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Lee 2016	!	+	!	+	!	-
Oh 2016	!	+	+	+	!	!
Zhang 2013	+	+	+	+	!	!

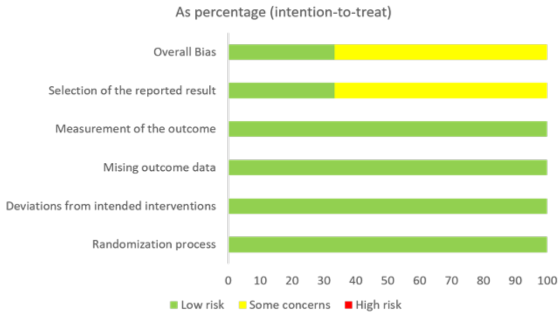
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 17. *Risk of bias assessment of the final elbow flexion strength outcome, measured in Strength Index (SI).*

12-month forearm supination strength, measured in kg						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+

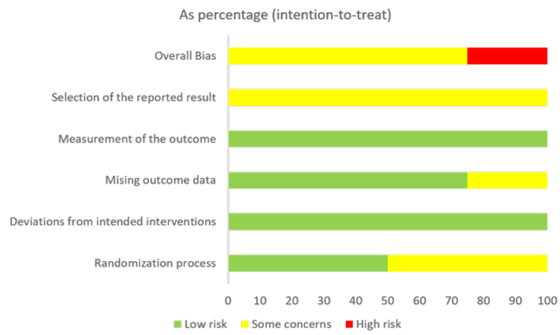
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 18. *Risk of bias assessment of the 12-month forearm supination strength outcome, measured in kilogram (kg).*

Forearm supination strength in SI, final data						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Hufeland 2019	+	+	+	+	!	!
Lee 2016	!	+	!	+	!	-
Oh 2016	!	+	+	+	!	!
Zhang 2013	+	+	+	+	!	!

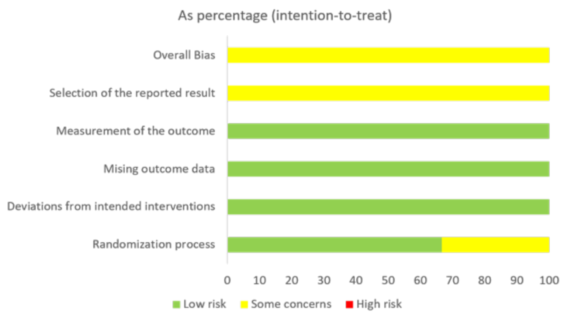
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 19. *Risk of bias assessment of the final forearm supination strength outcome, measured in Strength Index (SI).*

6-month Constant score						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Mardani 2018	!	+	+	+	!	!

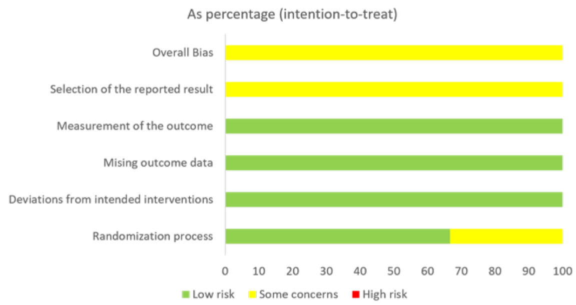
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 20. *Risk of bias assessment of the 6-month Constant score outcome.*

12-month Constant score						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Mardani 2018	!	+	+	+	!	!

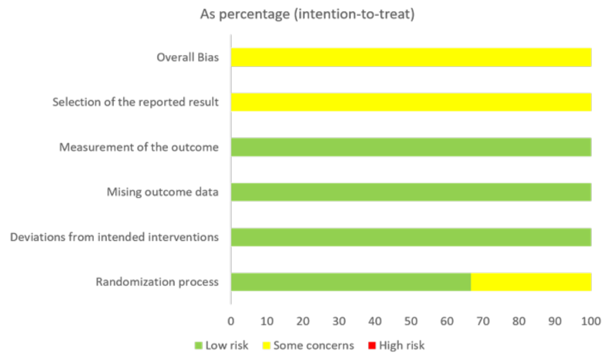
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 21. *Risk of bias assessment of the 12-month Constant score outcome.*

Final Constant scores						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
DeCarli 2012	!	+	+	+	!	!
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Mardani 2018	!	+	+	+	!	!
Zhang 2013	+	+	+	+	!	!

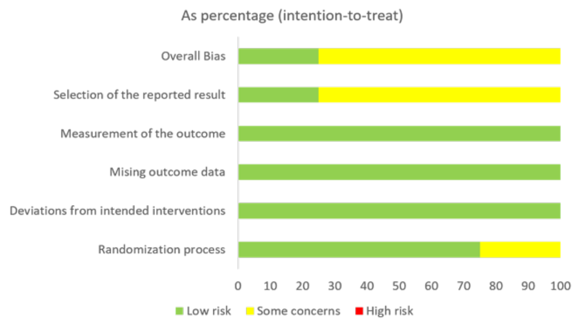
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 22. *Risk of bias assessment of the final Constant score outcome.*

Final ASES scores						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Belay 2019	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Oh 2016	!	+	+	+	!	!

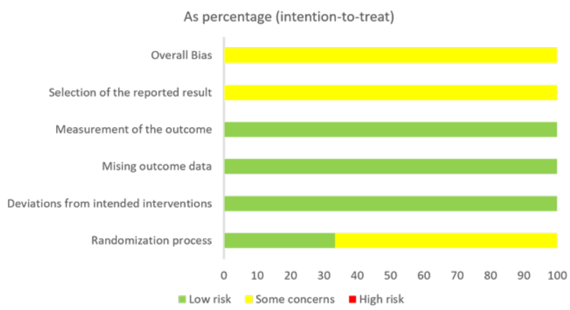
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 23. *Risk of bias assessment of the final American Shoulder and Elbow Surgeons (ASES) score outcome.*

Final SST scores						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
DeCarli 2012	!	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Mardani 2018	!	+	+	+	!	!

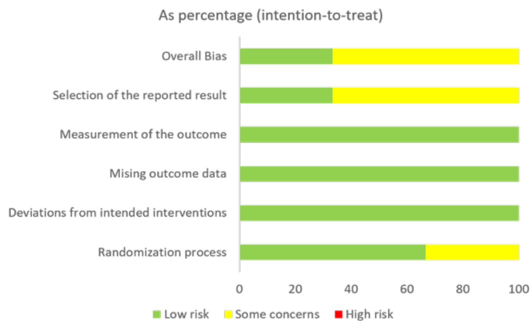
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 24. *Risk of bias assessment of the final Simple Shoulder Test (SST) score outcome.*

Pain on VAS, 3-month results						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Belay 2019	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Zhang 2019	!	+	+	+	!	!

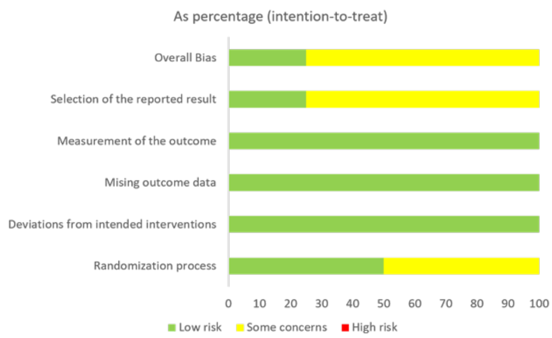
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 25. *Risk of bias assessment of the 3-month pain levels on the Visual Analog scale (VAS) outcome.*

Pain on VAS, 6-month results						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Mardani 2018	!	+	+	+	!	!
Zhang 2019	!	+	+	+	!	!

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 26. *Risk of bias assessment of the 6-month pain levels on the Visual Analog scale (VAS) outcome.*

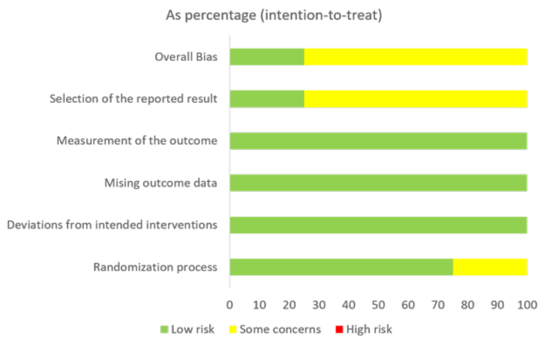
Pain on VAS, 12-month results						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
García-Rellan 2020	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Mardani 2018	!	+	+	+	!	!
Zhang 2019	!	+	+	+	!	!

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.

Supplementary Figure 27. *Risk of bias assessment of the 12-month pain levels on the Visual Analog scale (VAS) outcome.*

Pain on VAS, 24-month results							
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Belay 2019	+	+	+	+	!	!
Castricini 2017	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Mardani 2018	!	+	+	+	!	!

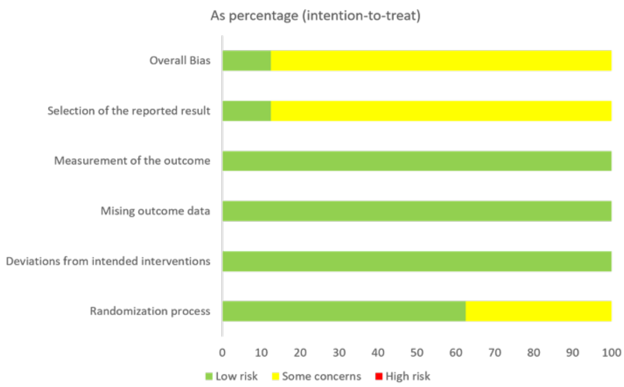
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 28. *Risk of bias assessment of the 24-month pain levels on the Visual Analog scale (VAS) outcome.*

Pain on VAS, final results						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Belay 2019	+	+	+	+	!	!
Castricini 2017	+	+	+	+	!	!
García-Rellan 2020	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Mardani 2018	!	+	+	+	!	!
Oh 2016	!	+	+	+	!	!
Zhang 2013	+	+	+	+	!	!
Zhang 2019	!	+	+	+	!	!

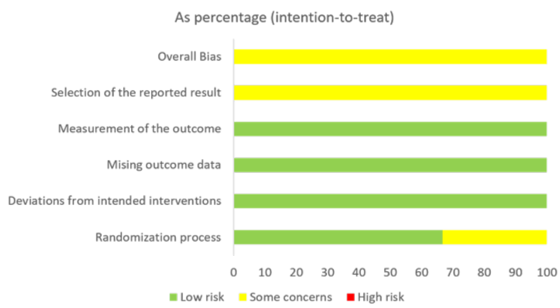
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 29. *Risk of bias assessment of the final pain levels on the Visual Analog scale (VAS) outcome.*

Number of bicipital cramping pain events at 6-month						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Oh 2016	!	+	+	+	!	!

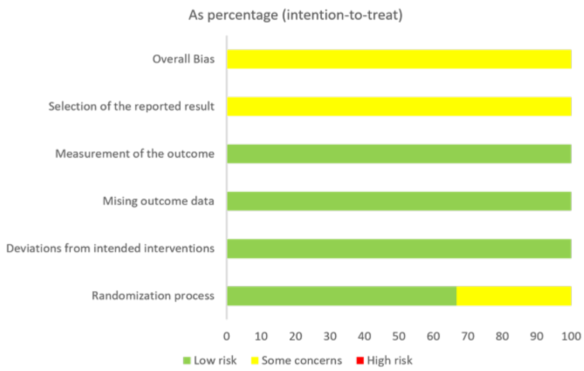
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 30. *Risk of bias assessment of the number of bicipital cramping pain events at 6 months outcome.*

Number of bicipital cramping pain events at final evaluation						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
García-Rellan 2020	+	+	+	+	!	!
Hufeland 2019	+	+	+	+	!	!
Mardani 2018	!	+	+	+	!	!
Oh 2016	!	+	+	+	!	!
Zhang 2013	+	+	+	+	!	!

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 31. *Risk of bias assessment of the number of bicipital cramping pain events at the final evaluation outcome.*

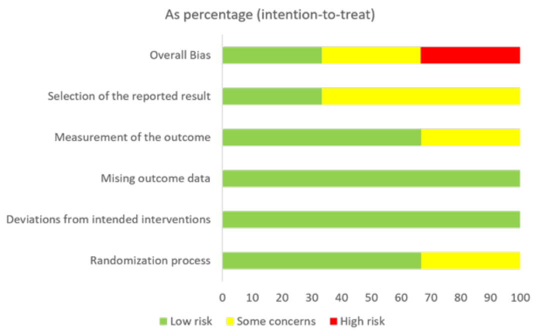
Number of bicipital groove pain events at final evaluation						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Belay 2019	+	+	+	+	!	!
García-Rellan 2020	+	+	+	+	!	!
Oh 2016	!	+	+	+	!	!

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.

Supplementary Figure 32. *Risk of bias assessment of the number of bicipital groove pain events at the final evaluation outcome.*

Number of Popeye-deformity events at 24-month						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Castricini 2017	+	+	+	+	!	!
MacDonald 2020	+	+	+	+	+	+
Mardani 2018	!	+	+	!	!	-

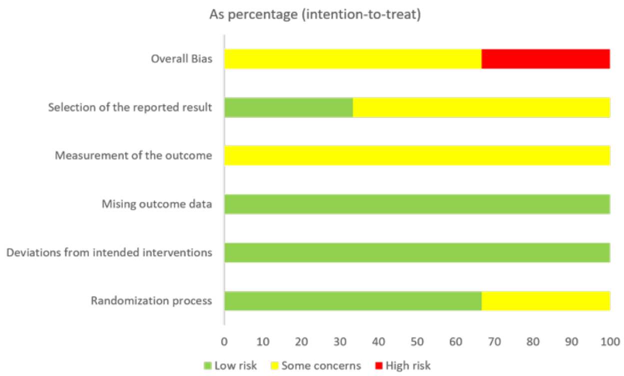
Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 33. *Risk of bias assessment of the number of Popeye deformity events at 24 months outcome.*

Operative time in minutes						
First author and year	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
MacDonald 2020	+	+	+	!	+	+
Zhang 2013	+	+	+	!	!	!
Zhang 2019	!	+	+	!	!	-

Green indicates low risk of bias, yellow indicates "some concerns", red indicates high risk of bias. Overall low risk of bias was given, where there was only green. It was given "some concerns", where there were one or two yellows, and high risk of bias was given, when the proccess resulted in three or more yellows or any reds.



Supplementary Figure 34. *Risk of bias assessment of the operative time outcome measured in minutes.*