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Subacromial Impingement Syndrome (SIS): Concepts in Pathophysiology, Genetics, Diagnosis, and Evidence-Based Management

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Abstract

Background: Subacromial impingement syndrome/pain syndrome (SIS/SAPS) is one of the most common causes of shoulder pain and functional limitation, affecting both the general population and individuals exposed to repetitive overhead activity. Despite extensive research, the pathogenesis, diagnostic criteria, and optimal management strategies for SIS/SAPS remain subjects of ongoing debate. Emerging evidence suggests that genetic susceptibility may contribute to individual variation in disease development and clinical presentation. **Objective:** The aim of this review was to analyze current concepts regarding the etiology, clinical presentation, diagnostic approaches, and treatment strategies for SIS/SAPS, with emphasis on contemporary evidence, evolving perspectives, and recently identified genetic and molecular contributors. **Methods:** A literature review was conducted mainly using publications indexed in Scopus, Web of Science, and PubMed. Original research articles, genome-wide association studies, systematic reviews, clinical guidelines, and high-quality randomized controlled trials addressing epidemiology, biomechanics, genetic susceptibility, imaging, conservative management, and surgical treatment of SIS/SAPS were analyzed and synthesized. **Results:** Current evidence supports a paradigm shift from viewing SIS/SAPS as a purely mechanical disorder to understanding it as a multifactorial clinical syndrome involving anatomical, biomechanical, functional, and genetic factors. Recent genome-wide association studies have identified single nucleotide polymorphisms associated with shoulder impingement and related rotator cuff pathology, implicating pathways involved in tendon and enthesis biology, inflammatory regulation, and pain processing. Clinical examination remains central to diagnosis, while imaging modalities such as radiography, MRI, and functional ultrasound play an adjunctive role in excluding alternative pathologies and guiding management. Conservative treatment—particularly individualized, supervised exercise ther-

apy combined with patient education and load modification—demonstrates superior long-term outcomes compared with isolated interventions such as corticosteroid injections. Recent high-quality trials question the routine use of surgical subacromial decompression in the absence of clear structural pathology. **Conclusion:** SIS/SAPS should be approached as a complex, heterogeneous condition influenced by both environmental and genetic factors, requiring patient-centered, evidence-based management. Incorporating genetic and biological insights alongside functional assessment and rehabilitation-focused treatment may enhance risk stratification and therapeutic decision-making. Judicious use of imaging and surgery remains essential to optimize clinical outcomes.

Keywords

Subacromial Impingement Syndrome (SIS), Subacromial Pain Syndrome (SAPS), Rotator Cuff, Genome-Wide Association Studies (GWAS), Single Nucleotide Polymorphisms (SNP)

1. Introduction of Background and Rationale

Shoulder pain affects a substantial portion of the global population, with a median prevalence of 16% (ranging from 0.67% to 55.2%), and is often associated with disorders of the rotator cuff and surrounding periarticular tissues [1]. The reported incidence of shoulder pain varied from 7.7 to 62 cases per 1000 persons per year, with a median incidence of 37.8 cases per 1000 persons annually [2]. Notably, rotator cuff impingement or supraspinatus syndrome stands out among these conditions. This pathology is commonly referred to in the international medical literature as "subacromial impingement syndrome" (SIS). In this context, the terms subacromial impingement syndrome (SIS) and subacromial pain syndrome (SAPS) are used interchangeably, reflecting a contemporary conceptual shift from a purely mechanical "impingement" model toward a symptom-based pain framework that better captures the condition's multifactorial biological, biomechanical, and functional nature. SIS, first described by C. Neer in 1972, is increasingly studied due to its impact on quality of life, especially in physically active individuals and those with repetitive overhead activity. The narrowing of the subacromial space compresses soft tissue structures, notably the supraspinatus tendon and subacromial bursa, leading to pain, inflammation, and eventual tendon degeneration. The aim of the current study was to analyze current concepts of etiology, clinical presentation, diagnostic approaches, and treatment strategies for SIS/SAPS with particular emphasis on contemporary evidence, functional mechanisms, and the role of modern imaging and rehabilitation methods.

2. Review Design and Literature Search Strategy

This article was prepared as a narrative literature review focusing on SIS/SAPS,

integrating current concepts of etiology, diagnosis, and management. The review methodology was designed to ensure comprehensive coverage of clinically and scientifically relevant publications while emphasizing contemporary evidence. A structured literature search was conducted using the international bibliographic databases, mainly Scopus, Web of Science Core Collection, and PubMed/Medline. Additional sources were identified through reference lists of key articles and clinical guidelines. The search strategy combined Medical Subject Headings (MeSH) and free-text terms, including but not limited to: *SIS/SAPS*, *shoulder impingement*, *rotator cuff disease*, *acromial morphology*, *functional ultrasound*, *magnetic resonance imaging*, *conservative treatment*, and *arthroscopic management*. Eligible publications included original clinical studies, randomized controlled trials, systematic and narrative reviews, bibliometric analyses, clinical practice guidelines, and consensus statements. Studies focusing on epidemiology, pathophysiology, clinical presentation, diagnostic methods (clinical examination and imaging), and treatment outcomes (conservative and surgical) were considered. Case reports, conference abstracts without full texts, and non-peer-reviewed sources were excluded.

Data extraction was performed manually by reviewing titles, abstracts, and full texts of relevant publications. Emphasis was placed on identifying recurring themes, areas of consensus and controversy, and recent methodological advances, particularly in imaging and rehabilitation strategies. The synthesis of findings was conducted qualitatively, without statistical meta-analysis, given the heterogeneity of study designs, diagnostic criteria, and outcome measures reported in the literature.

The structure and content of the review were aligned with contemporary academic standards for review articles in orthopedic and sports medicine journals, ensuring coherence with clinical relevance and translational applicability. The manuscript builds upon and systematizes the thematic framework presented in the source document provided by the authors.

3. Current Evidence and Emerging Perspectives

3.1. Epidemiology and Multifactorial Pathophysiology of Subacromial Impingement Syndrome

Recent meta-analyses confirm that SIS accounts for over 60% of shoulder-related clinical presentations [3]. The multifactorial etiology includes biomechanical dysfunction, scapular dyskinesia, acromial morphology, and systemic factors such as obesity and diabetes mellitus. Shoulder pain represents a highly prevalent musculoskeletal complaint, affecting approximately 7 - 26% of the global population [4] [5]. Shoulder pain is responsible for work-related disability and paid sick leave, underscoring its substantial socioeconomic impact [6]. SIS is particularly common among individuals exposed to repetitive or sustained verhead activity, including those engaged in heavy physical labor and athletes such as throwers, swimmers, and baseball players.

Genetic and Epigenetic Determinants of Subacromial Impingement Syndrome (SIS) and Rotator Cuff Pathology

Currently, considerable attention is being directed toward investigating the genetic and epigenetic factors involved in disease development [7]. SIS is a *clinical syndrome* that usually reflects a spectrum of subacromial pain conditions—most commonly rotator cuff tendinopathy/degeneration with variable bursitis and, in some patients, partial or full-thickness rotator cuff tearing. Because SIS is a "final common phenotype" with multiple contributing mechanisms (tendon matrix failure, inflammatory signaling, pain sensitization, and sometimes bony/soft-tissue anatomy), genetic susceptibility is expected to be polygenic and pathway-based rather than driven by a single gene [8]. Family and population studies in rotator cuff disease (a close biological neighbor of SIS) support inherited predisposition, and modern genomic studies now directly identify SIS/impingement risk loci and shared genetic architecture with rotator cuff disease [9]. The strongest direct evidence that impingement has a heritable component comes from genome-wide association studies (GWAS) using large biobank-scale phenotypes. Inherited variants set SIS baseline risk, while epigenetic regulation helps explain why the same genotype can produce different clinical SIS trajectories depending on age, load, and systemic milieu. Kim and colleagues conducted a genome-wide association study of shoulder impingement and integrated the results with previously published data on rotator cuff tears. This analysis identified four genome-wide significant loci located near LOC100506457, LSP1P3, LOC100506207, and MIS18BP1/LINC00871, as reported in the "*Journal of Shoulder and Elbow Surgery*". These findings indicate that the risk of subacromial impingement syndrome is partly genetically determined. The identified risk variants are thought to influence disease development through effects on tendon and enthesis biology, immune and inflammatory regulation, and pain processing pathways, depending on the specific locus and its downstream gene regulatory mechanisms. Because SIS often reflects intrinsic cuff tendon pathology, it is important that rotator cuff tearing/tendinopathy also shows reproducible genetic associations. Tashjian *et al.* identified loci associated with rotator cuff tearing, including targets such as ZNF804A, GLCCI1, and THSD7A, and combined multiple population resources to strengthen evidence [10]. In many patients, "impingement" symptoms emerge when genetically susceptible tendon tissue is exposed to normal aging/mechanical load; genetics can lower the threshold at which tendon matrix homeostasis fails, promoting tendinopathy that clinically presents as SIS. Importantly, genetic variants influencing tendon matrix composition, collagen organization, inflammatory regulation, and mechanotransduction may lower the biological threshold at which repetitive or otherwise physiological mechanical loading results in tendon microdamage, failed repair, and clinically manifest subacromial pain. In this context, mechanical factors such as overhead activity, altered scapulohumeral kinematics, or age-related loading do not act independently but rather interact with genetically primed tendon tissue, accelerating degenerative and inflammatory processes that culminate in SIS/SAPS symptoms. GWAS have identified several single nu-

cleotide polymorphisms (SNPs) associated with shoulder impingement risk. Two SNPs were shown to be associated with age at rotator cuff tear diagnosis. This phenomenon had been identified within the SLC39A8 gene (rs13107325) and the STXBP6 gene (rs11850957). Both variants are relatively common, with minor allele frequencies of 9% and 25%, respectively, in the study population. Notably, rs13107325 in SLC39A8 was previously identified through a meta-analysis combining a genome-wide association study of shoulder impingement from the UK Biobank with a GWAS of rotator cuff tears from the Kaiser Permanente Research Bank [11].

Beyond common SNPs of small effect, pedigree and sequencing studies suggest that some families carry rarer variants that meaningfully increase risk. In high-risk families, rare coding variants were identified in genes involved in TGF-β signaling and mechanobiology (e.g., RUNX1, ADAM12, TGFBR2, LTBP1, MAP3K genes) with follow-up signals including PDLIM7 and APBB1 in validation steps [12]. SIS in these families may represent a genetically primed "intrinsic tendon degeneration" phenotype, where normal loads trigger accelerated matrix breakdown and tear progression, producing impingement-like pain. Even when loci are not "tendon-collagen genes," they often converge on a small set of biological themes relevant to SIS. Genetic variation that alters collagen assembly, cross-linking, or matrix turnover can weaken supraspinatus/infraspinatus tendon and the enthesis, promoting tendinopathy and secondary subacromial pain. GWAS + expression follow-up designs explicitly aim to connect loci to tendon tissue expression changes after tearing [9].

SIS symptoms frequently correlate with bursal and tendon inflammatory signaling. Genetic approaches such as Mendelian randomization (MR) can test whether upstream inflammatory mediators are plausibly causal in rotator cuff pathology. A recent MR study evaluated circulating inflammatory proteins for causal links to rotator cuff tears, illustrating how inherited variants can be used to probe inflammatory pathways relevant to the broader SIS spectrum [13]. Subacromial bursa biology matters for pain and motion restriction in cuff disease. Transcriptome-level studies of subacromial bursa tissue (e.g., comparing rotator cuff tear patients with/without adhesive capsulitis) show genome-wide expression differences that can interact with inherited susceptibility (gene regulation, immune programs, fibrosis) [14]. Genetics also shapes exposures that increase SIS risk (adiposity, metabolic traits, smoking propensity, activity patterns). MR studies specifically applied to SIS/subacromial impingement and to shoulder pain outcomes support causal contributions from modifiable factors using genetic instruments and that rotator cuff injury may be causally linked to SIS [15].

SIS is strongly modified by mechanical loading and aging-classic triggers for epigenetic remodeling (DNA methylation, histone marks, non-coding RNAs). For example, age- and load-related changes in DNA methylation may downregulate genes involved in collagen synthesis, extracellular matrix remodeling, and tendon repair (such as those regulating TGF-β signaling or collagen turnover), thereby

impairing the ability of rotator cuff tendons to adapt to repetitive mechanical stress. Concurrently, hypomethylation of pro-inflammatory gene promoters in tendon or subacromial bursa tissue may enhance inflammatory signaling in response to mechanical overload, contributing to persistent pain and delayed resolution of symptoms despite similar external loading conditions.

Recent studies of rotator cuff diseases suggest that in late-stage rotator cuff tears, epigenetic factors play an important role in disease progression [16] [17]. Systematic reviews of recent research data describe observed epigenetic changes (including DNA methylation patterns and regulatory RNAs) in rotator cuff tendinopathy/degenerative tears. Wang Q and colleagues analyzed RNA sequencing–based transcriptional profiles of subacromial bursa samples from patients with rotator cuff tears, including those with concomitant adhesive capsulitis. The study expanded existing knowledge of differentially expressed gene profiles in subacromial bursa tissue from patients with rotator cuff tears, providing new insights into the regulation of gene transcription. [18]. Reviews on shoulder impingement syndrome (SIS) implicate miRNAs as regulators of inflammation, degeneration, and fatty degeneration of muscles in rotator cuff pathology—processes that often coexist with SIS [19]. However, current genetic signals are not yet strong enough for routine SIS genetic screening, but they already help define biologically coherent subtypes (matrix-dominant vs inflammation-dominant vs pain-sensitization–dominant) [9]. Recognition of emerging biological subtypes (e.g., matrix-dominant degeneration, inflammation-dominant pathology, and pain-sensitization-dominant phenotypes) has important clinical implications, as these subgroups may differ in their response to mechanical loading, anti-inflammatory interventions, and neuromodulatory rehabilitation strategies. From a personalized medicine perspective, patients with matrix-dominant subtypes may benefit most from carefully dosed, progressive loading programs aimed at restoring tendon homeostasis, whereas inflammation-dominant phenotypes may require greater emphasis on load modification and short-term anti-inflammatory strategies, and pain-sensitization-dominant subtypes may respond better to education, graded exposure, and central pain-targeted interventions.

Nevertheless, individuals with higher inherited risk may benefit most from early, load-optimized strengthening programs and aggressive management of metabolic/inflammatory comorbidities (supported indirectly by MR-style causal inference for lifestyle factors) [14].

3.2. Clinical Presentation and Functional Impact

Clinically, patients most often report pain localized to the anterior aspect of the shoulder joint, which is frequently exacerbated by overhead movements and during nighttime, especially when lying on the affected side. In many cases, symptom onset is insidious, developing gradually over several months without a clearly identifiable traumatic event. Consequently, early manifestations are often underestimated or attributed to transient fatigue or overuse. On physical examination,

the shoulder region may appear largely unchanged, despite the presence of significant functional impairment and pain, highlighting the need for a systematic diagnostic approach and justifying further clinical and instrumental evaluation prior to therapeutic decision-making.

Degenerative changes of the acromioclavicular joint represent an important contributing factor in the development of subacromial impingement syndrome. In particular, osteophytes forming on the inferior surface of the acromioclavicular joint may encroach upon the subacromial space and provoke impingement. In patients presenting with persistent clinical symptoms and radiographic evidence of osteophyte formation, surgical resection of the acromioclavicular joint may be considered when conservative treatment proves ineffective. Traditionally, SIS/SAPS was framed as mechanical "pinching" of rotator-cuff-related tissues in a narrowed subacromial space, causing pain and function loss. SIS/SAPS remains one of the most common presentations of shoulder pain in primary/secondary care, affecting work and sport participation—especially in overhead athletes and manual workers. Impingement syndrome, also known as subacromial syndrome, represents a disorder of normal shoulder joint function in which the rotator cuff tendons repeatedly contact the scapular process, referred to as the acromion. This anatomical interaction underlies the alternative terms *subacromial conflict* and *SIS* used in the medical literature. Although shoulder impingement syndrome was previously regarded as a distinct nosological entity, contemporary scientific literature increasingly conceptualizes it as a constellation of clinical symptoms arising from the interaction of multiple anatomical structures. The prevailing hypothesis underlying the development of impingement syndrome is based on a pathophysiological mechanism in which various components of the shoulder joint enter into mechanical conflict. This process primarily involves the functional zone of the rotator cuff, with the morphology of the acromion considered one of the principal extrinsic factors contributing to impingement. According to the classic description of subacromial impingement syndrome by C. Neer, the condition develops when the supraspinatus tendon is compressed between the greater tubercle of the humerus, the anterior surface of the acromion, and the coracoacromial ligament. This mechanical compression results in progressive tendon injury, followed by the development of inflammatory and degenerative changes within the affected tissues. During movements such as shoulder abduction, flexion, and internal rotation, the humeral head migrates superiorly and approaches the anteroinferior margin of the acromion. This displacement leads to a reduction in the subacromial space, which under normal conditions measures approximately 1.0 - 1.5 cm in width. The patient's pain is primarily attributable to increased pressure exerted by the humeral head on the rotator cuff tendons and the subacromial bursa following this narrowing. Recurrent mechanical compression promotes tendon inflammation, which in turn contributes to degenerative changes and chronic reduction of the subacromial space [13]. The results obtained by Wang, Y. *et al.* suggest a possible association between genetically predicted levels of IL-20, Leu-

kemia inhibitory factor, Signaling lymphocytic activation molecule (SLAM), and the risk of rotator cuff tears, supported by inverse-variance weighted analyses and consistent effect directions across sensitivity analyses.

C. Neer described three stages in the progression of shoulder impingement syndrome. The first stage is characterized by edema and hemorrhage resulting from initial impingement. The second stage involves fibrosis and irreversible structural changes of the tendons. The third stage is defined by partial or complete tendon rupture, accompanied by chronic pain and a longstanding fibrotic process. Major risk factors associated with subacromial impingement syndrome include obesity, excessive or repetitive physical overload, and endocrine disorders, with diabetes mellitus being of particular significance. Functional contributors to subacromial impingement syndrome are less extensively described in the literature; however, existing concepts are of considerable clinical interest and form an important basis for modern treatment strategies. These functional factors include scapular dyskinesia, anterior scapular tipping syndrome, anterior translation of the humeral head, superior translation of the humeral head, and inferior rotation of the humeral head.

Recent health-services research shows that even when evidence-based care exists, real-world adherence can be limited. For example, a Danish nationwide cohort (3306 patients) reported that less than half of patients in secondary care adhered to guideline-based management and many still had unacceptable symptoms after treatment [20]. The relationship between subacromial impingement and rotator cuff pathology has long been a subject of debate within the scientific community. Nevertheless, current evidence supports a multifactorial etiology involving both extrinsic and intrinsic mechanisms. The principal consequences of subacromial impingement syndrome include impairment of occupational and physical function, as well as the development of disability.

Subacromial impingement syndrome is characterized by pathological changes in several soft tissue structures within the subacromial space, including the subacromial-subdeltoid bursa, the tendon of the long head of the biceps brachii, and the distal portion of the supraspinatus tendon. Progressive degeneration of these structures may ultimately lead to partial and, subsequently, complete ruptures of the rotator cuff tendons. Several authors have emphasized the significant role of acromial morphology in the etiology of this pathological process, underscoring the importance of detailed investigation of this anatomical structure. Clinically, the most common manifestations of impingement syndrome include shoulder pain, muscle weakness, and restricted range of motion. Pain typically intensifies during overhead activities and at night, particularly when the patient lies on the affected shoulder. The upper limbs play a crucial role in daily human activity, enabling the performance of a wide range of functional tasks.

During arm elevation, the subacromial space progressively narrows, leading to mechanical compromise of the muscles and tendons passing through this region. As a result, activities involving overhead movements become difficult and painful.

In most cases, impingement syndrome develops due to inflammatory changes, microtrauma, mechanical compression, and degenerative wear of the periarticular structures caused by repetitive friction. Less frequently, the condition is associated with congenital or genetic factors, such as anatomical variations in the shape of the scapula or acromion.

Shoulder impingement syndrome is most commonly observed in individuals whose occupations require prolonged static or repetitive work with the arms elevated, including fitters, construction workers, painters, plasterers, and individuals performing sustained physical labor in domestic settings. Early symptoms are often misinterpreted by patients as ordinary fatigue or transient muscle strain following prolonged activity, leading to delayed medical consultation. If left untreated, the condition may progress and ultimately necessitate surgical intervention.

3.3. Clinical Assessment and Provocative Testing

At present, there are simple and highly accurate methods for identifying subacromial syndrome and differentiating it from other shoulder pathologies. Clinical examination plays a central role in the initial diagnostic process, and a number of practical tests demonstrate high diagnostic reliability. One commonly used approach is the impingement test, during which the patient elevates the arm along the lateral arc. An increase in pain as the arm passes through the mid-range of this arc is considered a characteristic and clinically significant finding. Regardless of pain intensity, the appearance of shoulder pain during such maneuvers warrants further medical evaluation to establish an accurate diagnosis. In this test, the arm is actively or passively abducted from the neutral position alongside the body, while attention is focused on the presence of pain between 70˚ and 120˚ of abduction. The occurrence of pain within this range is regarded as indicative of supraspinatus tendon involvement. Another widely applied clinical sign is the Neer impingement symptom, in which the examiner stabilizes the patient's scapula with one hand while passively elevating the arm in the scapular plane with forward, upward, and medial pressure. The reproduction of marked pain during this maneuver suggests compression of the subacromial structures. In their assessment of the shoulder joint, C. Gerber and A. Sebesta employed a modified version of the Neer test, which involved forward flexion of the shoulder to 80˚ - 90˚ with internal rotation, followed by forced flexion to approximately 140˚. The test was considered positive when pain was elicited in the anterior region of the shoulder joint. Other clinical tests were found to demonstrate comparatively low specificity and sensitivity.

Patients typically report pain radiating from the acromial region to the midhumerus, which is exacerbated by overhead activities and by lying on the affected side. Reduced shoulder mobility and nocturnal pain that interferes with sleep are also common reasons for seeking medical attention. Secondary to pain, patients may develop muscle weakness and joint stiffness. The onset of symptoms often

dates back several weeks or months, and patients usually do not report a specific precipitating event or traumatic injury. A detailed clinical history is therefore essential, focusing on the characteristics of the pain, factors that exacerbate, alleviate, or provoke symptoms, as well as the presence of repetitive microtrauma and the physical demands of daily activities. Although temporary symptom relief may be achieved through rest, nonsteroidal anti-inflammatory medication, and cryotherapy, identifying the underlying cause of symptom recurrence requires careful evaluation of activity-related triggers and the chronicity of the pain.

Physical examination of the shoulder includes inspection, palpation, assessment of both active and passive range of motion, and the application of specific provocative tests. Weakness during abduction and external rotation may be observed on the affected side, and the presence of muscle atrophy should be carefully evaluated. Palpation frequently elicits pain in the region of the coracoid process. Special clinical tests play a key role in the diagnosis of subacromial impingement syndrome. Commonly used examination methods include the Hawkins–Kennedy test, the Neer impingement test, the Jobe (empty can) test, and the painful arc test, all of which are widely recognized in clinical practice as valuable diagnostic tools.

Clinically, differentiating this type of compression syndrome from subcoracoid impingement is often challenging, as the affected region is located in close proximity to the coracoid process of the scapula and the localization of pain may be indistinct. Palpation alone is usually insufficient to accurately determine the site of pathology, since pain in the region of the intertubercular groove may also reflect inflammation of the tendon of the long head of the biceps brachii, a condition that is not necessarily related to a compression syndrome. Consequently, instrumental diagnostic methods are of particular importance in such cases.

3.4. Imaging and Instrumental Diagnostics: Static and Dynamic Assessment

Imaging techniques such as ultrasound and magnetic resonance imaging are most informative when symptoms persist despite an adequate course of rehabilitation, when marked weakness or a history of trauma raises suspicion of a rotator cuff tear, or when alternative diagnoses and red flags must be excluded. It should be noted that magnetic resonance imaging can only indirectly support the diagnosis of anterior-superior impingement syndrome by demonstrating inflammatory, degenerative, or traumatic changes in the anterosuperior portion of the rotator cuff. In contrast, the presence of mechanical compression and narrowing characteristic of anterior-superior impingement syndrome, as well as instability of the tendon of the long head of the biceps brachii and its contact with the anterosuperior aspect of the glenoid, can be more directly confirmed through high-resolution functional ultrasound examination, provided that dynamic assessment is performed by an experienced examiner. Although several publications report that the sensitivity of patient history and physical examination in diagnosing shoulder impingement syndrome may reach up to 90%, imaging modalities are frequently re-

quired to exclude alternative or concomitant pathologies. Instrumental and radiological diagnostic methods are typically selected based on the findings of the clinical examination or are prescribed following the initial assessment. These modalities may include radiography, ultrasound examination, magnetic resonance imaging, or arthroscopic evaluation, each of which provides additional information regarding the condition of the subacromial space, rotator cuff tendons, and surrounding anatomical structures. Standard shoulder radiography performed in the anteroposterior and scapular Y projections facilitates the detection of occult structural abnormalities. In addition, parameters such as the critical shoulder angle and the acromiohumeral index, which quantify the lateral extension of the acromion relative to the glenoid cavity, can be reliably assessed on anteroposterior radiographs of the shoulder. The application of advanced instrumental diagnostic techniques, particularly magnetic resonance imaging and functional ultrasound, has significantly enhanced the ability to accurately visualize pathological changes within specific components of the musculoskeletal system. These modalities have enabled researchers to distinguish several types of shoulder impingement syndromes involving different osseous, muscular, and ligamentous structures. Notably, a study published in 2023 employed dynamic quantitative ultrasonography to assess subacromial motion parameters and demonstrated measurable differences in acromiohumeral distance and movement patterns in patients with subacromial impingement syndrome. These findings highlight a contemporary shift toward dynamic, rather than purely static, evaluation of shoulder biomechanics. Beyond its diagnostic value, dynamic ultrasound can directly inform individualized rehabilitation by identifying specific movement-related abnormalities, such as altered scapular upward rotation, delayed scapular posterior tilt, or excessive superior translation of the humeral head during arm elevation. Recognition of these dynamic patterns allows clinicians to tailor rehabilitation programs toward targeted scapular stabilization, rotator cuff loading, and motor control retraining, rather than applying uniform exercise protocols across heterogeneous SIS/SAPS presentations. In this way, functional ultrasound serves as a bridge between biomechanical assessment and precision rehabilitation, enabling real-time linkage between observed kinematic deficits and specific therapeutic interventions.

3.5. Evidence-Based Management Strategies

The selection of a treatment strategy is determined by the nature and severity of pathological changes in the shoulder joint as identified through magnetic resonance imaging, ultrasound examination, and clinical assessment. High-quality evidence continues to challenge routine decompression for SAPS. A 2025 BMJ multicenter randomized trial reported no long-term benefit of arthroscopic subacromial decompression compared with placebo surgery for subacromial pain [21]. In parallel, expert commentary in "*Arthroscopy*" has argued that arthroscopic treatment for subacromial pain should no longer be routinely offered, aligning with the broader de-implementation trend [22]. In the absence of complete rupture of

the medial retinaculum of the tendon of the long head of the biceps brachii, conservative management may be indicated, including the use of nonsteroidal anti-inflammatory drugs and subacromial administration of glucocorticoids. Injection into the subacromial space allows therapeutic delivery while minimizing direct adverse effects on tendon tissue and provides symptomatic relief through the anti-inflammatory action of corticosteroids.

In cases involving rupture of the aforementioned structures, arthroscopic reconstructive procedures of the shoulder joint are typically performed. When rupture or advanced degenerative changes of the tendon of the long head of the biceps brachii are present, tenodesis or tenotomy is indicated. If the tendon itself remains intact but the medial retinaculum is torn, arthroscopic reconstruction of the retinaculum is undertaken.

A research group led by R. Roddy at Keele University (United Kingdom) evaluated the effectiveness of ultrasound-guided intra-articular glucocorticoid injections in the shoulder joint and compared these with conservative management consisting of supervised rehabilitation and independently performed standard exercises targeting the rotator cuff and shoulder musculature [23]. Outcomes were assessed using the Shoulder Pain and Disability Index at 6 weeks, 6 months, and 12 months following initiation of treatment. The study demonstrated no significant advantage of ultrasound-guided injections, whereas an individually tailored, supervised exercise program was found to yield superior clinical outcomes.

Across contemporary pathways and guidelines, structured exercise therapy (often rotator cuff + scapular stabilizer strengthening, graded exposure, and load management) remains the core treatment strategy [24].

A 2025 JOSPT clinical practice guideline on rotator cuff–related shoulder pain (which overlaps heavily with SAPS populations/labels) reinforces an evidence-based non-surgical approach emphasizing assessment, education, and progressive rehab [25].

4. Conclusion

Subacromial impingement syndrome/subacromial pain syndrome (SIS/SAPS) represents a highly prevalent and clinically important cause of shoulder pain, associated with significant functional impairment, reduced quality of life, and substantial socioeconomic consequences. Accumulating evidence indicates that SIS/SAPS should no longer be regarded as a purely mechanical condition caused by simple structural encroachment within the subacromial space. Instead, it is increasingly recognized as a complex, heterogeneous clinical syndrome arising from the interplay of anatomical variation, altered biomechanics, tendon and bursal pathology, inflammatory processes, functional motor control deficits, and individual susceptibility. Recent advances in genetic and molecular research further support this multifactorial model, demonstrating that inherited variation contributes to rotator cuff pathology and impingement-related pain through pathways involved in tendon biology, inflammation, and pain processing. While these ge-

netic findings are not yet applicable to routine clinical screening, they provide important insights into disease mechanisms and help explain interindividual differences in clinical presentation and response to loading and rehabilitation. From a clinical perspective, careful history taking and targeted physical examination remain the foundation of diagnosis, with imaging reserved for excluding alternative diagnoses, identifying structural pathology, and guiding management in selected cases. Contemporary high-quality evidence consistently supports conservative, exercise-based management as the first-line treatment for SIS/SAPS. Individually tailored, supervised rehabilitation programs combined with patient education and load modification demonstrate superior and more durable outcomes compared with isolated interventions such as corticosteroid injections. Moreover, recent randomized trials and expert consensus challenge the routine use of surgical subacromial decompression in the absence of clearly defined structural pathology. Optimal management of SIS/SAPS requires a patient-centered, evidence-based approach that integrates functional assessment, rehabilitation-focused treatment, and judicious use of imaging and surgery. Continued integration of biomechanical, genetic, and clinical insights will further refine diagnostic frameworks and therapeutic strategies, ultimately improving outcomes for individuals affected by this common shoulder condition.

5. Future Directions

Despite significant advances, several key questions remain unanswered and warrant focused future investigation. Longitudinal cohort studies are needed to validate genetic risk scores and determine whether identified susceptibility variants can prospectively predict the onset, severity, or progression of SIS/SAPS under defined mechanical loading exposures. In parallel, translational studies integrating genetic, epigenetic, imaging, and clinical data are required to establish biologically meaningful patient stratification frameworks. Importantly, randomized clinical trials comparing subtype-specific rehabilitation strategies—tailored to matrix-dominant, inflammation-dominant, or pain-sensitization-dominant phenotypes—are necessary to determine whether precision-based exercise and load-management protocols improve outcomes compared with current standardized approaches. Further research should also explore whether dynamic imaging biomarkers and modifiable epigenetic signatures can be used to monitor treatment response and guide adaptive rehabilitation over time.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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