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Joint and sternal cracking in physically active individuals – clinical significance and current evidence

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Abstract

Introduction and purpose

Joint cracking and audible sounds perceived in the sternum or anterior chest wall are common in physically active individuals. Although isolated sounds without red flags are usually physiological, anterior chest symptoms frequently raise concern because they may be misinterpreted as cardiopulmonary. This narrative review summarizes current evidence on mechanisms and clinical relevance of joint and sternal/chest wall cracking in active populations.

State of knowledge

Evidence from biomechanical and clinical literature suggests that sternal/chest wall cracking most often reflects musculoskeletal causes—sternoclavicular joint dysfunction, costosternal/costochondral involvement, or slipping rib syndrome—and may also occur with overload or stress-related injury. Parallel research in synovial joints, particularly the knee, shows that acoustic emission (AE) and vibroarthrography (VAG) features correlate with joint function and can support machine-learning discrimination between healthy and pathological states; however, heterogeneity of sensors, tasks, and signal-processing pipelines limits comparability and clinical translation.

Conclusions

In the absence of pain, swelling, instability, functional limitation, or systemic symptoms, joint sounds alone should not be considered pathological. For sternal/anterior chest wall cracking, assessment should prioritize exclusion of urgent cardiopulmonary causes, evaluation of training load/technique, and targeted examination of the sternoclavicular joint and rib–sternum complex, with imaging when indicated. AE/VAG approaches are promising adjuncts for research and longitudinal monitoring, but routine clinical use requires standardized protocols and prospective validation.

Key words: joint cracking; sternum; chest wall; slipping rib syndrome; acoustic emission; vibroarthrography.

Introduction

Isolated joint sounds (e.g., cracking, popping, clicking) in the absence of red flags are most often physiological. After urgent conditions have been excluded, cracking perceived in the sternum or anterior chest wall commonly reflects musculoskeletal causes—such as sternoclavicular joint (SCJ) dysfunction, costosternal/costochondral involvement, slipping rib syndrome—or overload/stress-related injuries in physically active individuals [1–11].This review aims to synthesize the current evidence on the mechanisms of joint sounds and sternal/anterior chest wall cracking in physically active populations, and to discuss their clinical relevance with respect to assessment and practical management [1–5, 9–12]. The literature on these phenomena is dispersed and spans biomechanical investigations as well as clinical observations [1–5, 12–17]. In parallel, there has been increasing interest in objective, signal-based approaches—particularly joint acoustic emission (AE) analysis and vibroarthrography (VAG)—for functional joint assessment. However, the clinical utility of these tools and their readiness for routine practice remain to be established through standardized protocols and robust validation [12–16, 18–19].

Audible cracking and snapping perceived in the sternum and anterior chest wall warrant specific clinical attention [2–5]. Although such symptoms are most frequently musculoskeletal in origin, careful differential diagnosis is required because their location may lead to misinterpretation as cardiopulmonary complaints [20]. Among physically active individuals, sternal or chest wall cracking is commonly reported in association with resistance training, intensive upper-limb work, and rapid increases in training load, particularly when technique is suboptimal or overload develops [6–8, 10].

In most cases, sounds originating from peripheral joints and the spine are physiological and not associated with structural damage or impaired musculoskeletal function [1, 15]. These sounds may reflect joint biomechanics, periarticular soft-tissue behavior, and neuromuscular adaptations related to habitual physical activity [16, 21]. Nevertheless, a subset of individuals report concomitant pain, perceived instability, or functional limitation, raising the possibility of clinically relevant pathology and the need for further evaluation [17, 22–23]. Joint sounds are highly prevalent in the general population and appear particularly common in athletes and physically active individuals [1, 12–13]. Despite this prevalence, their clinical meaning remains ambiguous, contributing to patient anxiety and inconsistent interpretation in routine care [12, 14].

Terminology and Clinical Phenotypes of Musculoskeletal Sounds

In clinical communication, “cracking” is often used as a catch-all term, yet patients describe a spectrum of sensations. A single crack or pop is usually brief, discrete, and may be followed by a period during which the sound cannot be reproduced. Clicking is typically repetitive and linked to a specific phase of a movement cycle, while snapping is often described as a sudden shift that may be audible or merely palpable. Crepitus is a coarse grinding or crackling sensation, frequently noticed during slow range-of-motion tasks. Clunking may suggest transient translation or subluxation, particularly in unstable joints.

Because these labels can bias clinical reasoning, the first task is to operationalize the symptom. Clinicians should determine whether the sound is isolated or repetitive, whether it occurs at rest or only under load, whether it is accompanied by pain, and whether it is associated with functional limitation. When athletes report an audible “sternal crack,” the localization is often imprecise; the perceived source may be the sternoclavicular joint, parasternal costal cartilage, costal margin, or adjacent thoracic spine. Mapping symptoms to a specific movement pattern is therefore more informative than relying on anatomical language.

A useful heuristic is to distinguish three phenotypes. Phenotype 1 is isolated, painless cracking with a refractory period (often minutes) before the sound can recur. Phenotype 2 is repetitive clicking or snapping that occurs reliably at a particular joint angle or movement phase. Phenotype 3 is coarse crepitus, perceived as grinding or crackling, which may be intermittent or continuous through range. Each phenotype has different pre-test probabilities for clinically relevant pathology, and each requires a slightly different assessment emphasis.

The psychological context deserves explicit attention. In sport settings, cracking is frequently interpreted as a marker of “wear and tear,” which can increase worry and symptom vigilance. Conversely, some individuals seek cracking for perceived relief or “resetting.” A neutral explanation, anchored in the absence or presence of red flags and in objective function, can reduce catastrophizing and help athletes maintain training consistency. Education should aim to shift attention from the sound itself to modifiable drivers such as load management, movement quality, and recovery.

Biomechanical Mechanisms of Synovial Joint Cracking

The most widely discussed mechanism for an isolated crack in a synovial joint is cavitation within synovial fluid during rapid separation of articular surfaces. Real-time cine MRI of metacarpophalangeal joints supports the concept that the audible event corresponds to rapid cavity formation (“cavity inception”) rather than the collapse of an existing bubble, and that the cavity can persist after the crack—findings consistent with tribonucleation [24]. This helps explain the characteristic refractory period and the frequent association of cracking with rapid traction or end-range stretching.

Cavitation-related cracking is influenced by joint geometry, the speed and magnitude of separation, synovial fluid properties, and baseline intra-articular pressure. In practice, this explains why cracking is more likely during warm-up or after immobility, when tissue stiffness and exploratory end-range movements are common. Importantly, cavitation is not synonymous with injury. In the absence of pain, swelling, instability, or functional decline, isolated cracking is usually a normal physiological phenomenon and should not prompt activity restriction.

Repetitive clicking and snapping more often reflect periarticular structures interacting with bony prominences or transiently catching and releasing. Tendon snapping, movement of synovial folds, meniscal or labral pathology, and transient impingement are typical examples. In some joints, repetitive sounds can occur without pathology because of individual anatomy and movement strategy; in others, the emergence of painful snapping may reflect overload or injury. The clinical challenge is therefore to interpret the sound in context and to avoid over-attributing structural damage on the basis of noise alone.

In the spine and costovertebral region, audible phenomena may arise from rapid changes in joint congruence, facet gapping, or soft-tissue interactions, and they can be elicited during manipulation or end-range rotation. These sounds are common and frequently painless. When symptoms are present, they often reflect a combination of local sensitivity, load tolerance, and movement variability rather than a single discrete lesion. This perspective is particularly relevant for anterior chest wall complaints where thoracic and rib mechanics can refer sensations to the parasternal region.

Epidemiology and Context in Physically Active Populations

Joint sounds are common across the lifespan, and observational studies suggest high prevalence even among asymptomatic individuals. In athletes and exercisers, exposure to repetitive loading, larger ranges of motion, high-velocity transitions, and contact or falls increases the likelihood that sounds are noticed or provoked. Athletes also tend to monitor their bodies closely; therefore, a small change in sensation can become highly salient, particularly when returning from an injury, increasing training volume, or attempting new movement skills.

Contextual factors influence whether a sound is benign or clinically relevant. Rapid increases in training load, reduced recovery, technique changes under fatigue, and strength or mobility deficits can increase stress on periarticular tissues. In such settings, a previously painless click may coexist with emerging overload, tendinopathy, or joint irritation. Conversely, in athletes with stable technique and progressive load progression, isolated painless sounds rarely predict injury and should not be used as a criterion to stop sport participation [12, 14].

Generalized joint hypermobility can increase the frequency of clicking or popping because of altered joint centering and increased translation. In the chest wall, hypermobility is a recognized contributor to excessive costal cartilage motion and may predispose to slipping rib syndrome and similar snapping phenomena, particularly in younger physically active populations [3, 25–26].

When Sounds Matter: Red Flags and Indicators of Pathology

Although most isolated cracking is physiological, certain features warrant further evaluation. In peripheral joints these include acute swelling, warmth or erythema, persistent or progressive pain, mechanical symptoms such as locking or recurrent giving way, neurological deficits, recent trauma, systemic symptoms (fever, weight loss, night pain), or a clear decline in sport performance attributable to the joint. A transition from longstanding painless clicking to painful snapping with loss of function should prompt targeted examination and, when appropriate, imaging or referral.

For sternal and anterior chest wall complaints, exclusion of urgent cardiopulmonary causes is essential, particularly when symptoms include dyspnea, syncope, palpitations, exertional chest pressure, hemoptysis, fever, or high thromboembolic risk. Once urgent causes are excluded, musculoskeletal conditions become more likely, but clinicians should still consider inflammatory arthritis (sternoclavicular swelling, morning stiffness), infection (erythema, fever, immunosuppression), and stress injury in athletes with focal tenderness and persistent pain.

A practical indicator of clinical relevance is the co-occurrence of sound, pain, and functional limitation. Sound in isolation rarely requires intervention. Sound with pain but preserved function often responds to load modification and targeted rehabilitation. Sound with pain plus progressive limitation, visible swelling, neurological symptoms, or systemic features should prompt investigation. This triage framework helps clinicians avoid both under-recognition of serious pathology and over-medicalization of benign cracking.

Methods (Literature Search and Evidence Synthesis)

This narrative review integrates biomechanical and clinical evidence on joint cracking and sternal/anterior chest wall cracking in physically active individuals. A structured search was conducted in PubMed and Google Scholar using combinations of terms related to joint sounds (“joint cracking”, “clicking”, “popping”, “crepitus”), chest wall sounds (“sternal clicking”, “sternoclavicular”, “manubriosternal”, “slipping rib syndrome”), and objective sound analysis (“acoustic emission”, “vibroarthrography”). The search covered publications from database inception to 10 January 2026 (last search: 10 January 2026) and prioritized English-language peer-reviewed literature. The search emphasized the most recent literature while including foundational studies that informed mechanistic understanding.

Discussion

The included publications clustered into two main streams. The first focused on objective characterization of joint sounds predominantly in the knee using AE and VAG, with signal processing approaches increasingly supported by machine learning methods [12–16, 18–19]. The second comprised clinical literature on sternal and anterior chest wall cracking and pain, including SCJ-related conditions and slipping rib syndrome, supported by cohort studies, surveys, case series, and case reports [2–11, 17].

The biomechanical stream included experimental and modeling work focused on synovial joint cracking mechanisms, along with methodological studies evaluating acoustic emission (AE) and vibroarthrography (VAG) as objective proxies of joint surface interactions. These studies emphasize acquisition conditions, feature stability, and the relationship between acoustic features and structural or functional measures of joint health [12–16, 18–19].

The clinical stream addressing sternal and anterior chest wall cracking consisted primarily of clinical reviews, case series, and case reports. These papers focus on differential diagnosis and practical management and highlight musculoskeletal causes such as sternoclavicular joint dysfunction, costochondral irritation, and slipping rib syndrome after cardiopulmonary conditions have been excluded [2–11, 25].

Across both streams, study heterogeneity is substantial. Definitions of “cracking” vary, outcome measures are inconsistent, and many studies rely on subjective symptom reporting. Consequently, the current evidence base supports pragmatic clinical algorithms and mechanistic plausibility rather than definitive diagnostic rules. This review therefore emphasizes structured assessment (red flags, symptom pattern, function) and outlines how objective acoustic methods may complement rather than replace standard clinical evaluation.

Sternal and Anterior Chest Wall Cracking

After cardiopulmonary etiologies are excluded, available evidence suggests that sternal/anterior chest wall cracking is frequently musculoskeletal in origin and may involve the SCJ, costosternal/costochondral structures, or slipping rib syndrome [2–5, 9, 11]. Clinical reports also document stress or overload injuries affecting the sternum and ribs in physically active individuals, particularly in the context of resistance training and high upper-limb demands [6–

8, 10]. These observations support a management approach that prioritizes load assessment and modification, targeted physical examination of the SCJ and rib–sternum complex, and imaging when symptom severity, persistence, or clinical suspicion warrants further evaluation [2–11]. In selected cases with refractory symptoms and identifiable structural contributors, etiological treatment strategies have been associated with meaningful improvement [4, 9].

Anatomical Considerations and Sites of Motion

The anterior chest wall couples respiration, trunk motion, and upper-limb loading. Audible or palpable "sternal" cracking can originate from the sternoclavicular joint (SCJ), the manubriosternal junction, costosternal or costochondral junctions, the xiphisternal region, or adjacent thoracic spinal and costovertebral structures. Small movements at these interfaces are normal during breathing and shoulder motion; however, increased laxity, altered movement patterns, or overload can make these micro-motions audible and clinically salient.

Symptom localization is often imprecise. A click perceived "in the sternum" may reflect SCJ translation near the medial clavicle, parasternal costal cartilage motion, lower costal margin slipping, or thoracic facet and rib mechanics. Assessment should therefore link symptoms to specific tasks. Overhead elevation, horizontal adduction, and heavy pressing tend to load the SCJ and upper costosternal region, whereas trunk rotation, deep breathing under load, and abdominal bracing can provoke motion at the lower costal margin.

Differential Diagnosis in Athletes and Exercisers

After urgent cardiopulmonary causes have been excluded, the differential diagnosis includes benign physiological cavitation, SCJ sprain or instability, manubriosternal irritation, costochondritis or Tietze syndrome, slipping rib syndrome (SRS), rib stress injury, sternal stress injury, and less commonly inflammatory arthropathies or infection. Pain provoked by specific lifting patterns (bench press, dips, ring work, overhead pressing) may indicate load-related irritation of the SCJ or parasternal attachments, whereas lower costal margin pain with clicking can point toward SRS.

Trauma should always be considered, particularly in contact sports or after falls. Even when plain radiographs are normal, costochondral sprain and intercostal muscle strain can cause painful clicking with deep breaths and trunk motion. Conversely, painless cracking without functional limitation is most often benign; the clinical priority is to determine whether the sound is simply an incidental finding or a marker of instability or overload that requires modification of training or further investigation.

Slipping Rib Syndrome

SRS is increasingly recognized as an under-diagnosed cause of anterior chest wall or upper abdominal pain with clicking or popping sensations. It is thought to arise from abnormal mobility of the anterior false ribs (typically ribs 8–10) due to laxity or disruption of interchondral attachments. The resulting intermittent subluxation can irritate the intercostal nerve and produce sharp, radiating pain as well as a palpable or audible “slip” [3, 25–26]. Athletes may report symptoms during twisting, sit-ups, heavy breathing under load, or transitions between trunk positions.

History and examination are often sufficient to raise suspicion. Patients frequently describe a reproducible click at the costal margin accompanied by pain that may radiate to the back or abdomen. The “hooking maneuver” aims to reproduce symptoms by lifting the costal margin anteriorly and superiorly; however, it can be uncomfortable and is not universally tolerated. Local anesthetic intercostal nerve blocks can serve both diagnostic and therapeutic roles, particularly when imaging is inconclusive.

Dynamic ultrasound has emerged as a practical adjunct to confirm abnormal rib cartilage motion and reproduce symptoms under provocation. Studies and clinical reports describe performing ultrasound during maneuvers such as active crunching or rib push to visualize slipping motion. Recent longitudinal experience suggests that dynamic ultrasound can support diagnosis and guide management pathways, especially in patients with persistent symptoms and equivocal clinical findings [27].

Management is stepwise. Initial care includes reassurance, modification of provoking activities, and symptom control, followed by rehabilitation emphasizing trunk control, rib mechanics, and graded return to sport. When pain is severe or persistent, intercostal nerve blocks may facilitate rehabilitation. Surgical intervention most commonly cartilaginous rib excision or stabilization techniques is generally reserved for refractory cases, and recent reviews describe evolving operative options with attention to recurrence risk and complication profiles [3, 25].

Sternoclavicular and Manubriosternal Sources

The SCJ is the only true synovial joint linking the upper limb to the axial skeleton and experiences substantial shear and torsional loads during pressing and overhead activity. In athletes, SCJ dysfunction can present as medial clavicular pain, clicking, or a sense of shifting near the joint. Contributing factors may include scapular dyskinesis, pectoralis minor tightness, thoracic hypomobility, and abrupt increases in pressing volume. Examination should assess SCJ tenderness, swelling, prominence, and apprehension with horizontal adduction and shoulder protraction, while also evaluating scapular and thoracic mechanics.

Manubriosternal and xiphisternal junctions can also generate audible phenomena, especially with deep breathing and trunk extension. Minor motion can be physiological, but focal tenderness or persistent pain raises suspicion of overload, osteitis, or inflammatory disease. In rare cases, stress injury of the sternum or adjacent rib attachments can occur in athletes exposed to repetitive upper-body loading. Persistent pain with focal bony tenderness should prompt imaging and load reduction until healing is confirmed.

Costochondritis and Other Inflammatory Conditions

Costochondritis is a common and generally benign cause of anterior chest wall pain characterized by reproducible tenderness at costochondral or costosternal junctions, typically without visible swelling. It can be precipitated by vigorous upper-extremity activity, coughing, or repetitive micro-trauma, and is diagnosed after excluding serious causes of chest pain. Management is usually conservative, with reassurance, topical measures, oral analgesics or anti-inflammatories, and gradual resumption of activity. Stretching and mobility programs may benefit patients with persistent symptoms [28].

Inflammatory arthropathies can involve the SCJ and anterior chest wall and may present with swelling, warmth, morning stiffness, and systemic features. Infection although uncommon should be suspected when there is fever, erythema, immunosuppression, intravenous drug use, or markedly elevated inflammatory markers. In such scenarios, urgent evaluation and appropriate specialist referral are required.

Imaging and Diagnostic Work-Up

Imaging is not routinely required for painless cracking in the absence of red flags. When symptoms persist or red flags are present, targeted imaging can support diagnosis and guide management. Plain radiographs may identify fractures or gross abnormalities, but cartilage lesions and subtle stress injuries can be missed. Ultrasound can evaluate superficial structures and, when performed dynamically, can support the diagnosis of SRS and guide local injections [27]. MRI can evaluate bone marrow edema in stress injuries, synovitis, inflammatory change, and adjacent soft-tissue pathology.

Diagnostic yield improves when imaging is tied to a specific clinical question (e.g., suspected sternal stress injury, SCJ synovitis, or dynamic rib motion consistent with SRS). Over-imaging in low-risk presentations may identify incidental findings and increase anxiety without improving outcomes. Therefore, imaging should be reserved for cases in which results are expected to change management decisions.

Synovial Joint Sounds and Acoustical Assessment (AE/VAG)

In the joint-sound stream, multiple studies reported associations between acoustical features and joint function, proprioception, and patient-reported knee status, and demonstrated that machine learning models can differentiate healthy joints from those exhibiting features consistent with pathology, including pre-radiographic states [14–16, 18–19]. At the same time, authors consistently highlighted major methodological limitations, including heterogeneous sensor types, recording conditions, movement tasks, preprocessing pipelines, and feature sets, which constrain comparability across studies and hinder translation to clinical practice [12, 14–15]. Thus, while AE/VAG-based approaches appear promising for monitoring and research applications, their role as routine clinical tools remains premature without protocol standardization and prospective validation in representative clinical populations [12–16, 18–19]. Wavelet-entropy feature extraction approaches and recent review-level syntheses further support the feasibility of VAG-based classification for knee disorders, while underscoring the need for standardization [29–30].

Principles of Acoustic Emission and Vibroarthrography

Acoustic emission (AE) refers to transient elastic waves generated by rapid energy release within a structure. In biological joints, AE and vibroarthrography (VAG) record vibrations produced by interactions of articular surfaces and periarticular tissues during movement. Unlike patient-reported sounds, these methods can capture sub-audible events and quantify signal properties such as amplitude, frequency distribution, temporal density, and burst patterns. The attraction of AE/VAG is that it can be implemented non-invasively, repeatedly, and at relatively low cost, which is particularly relevant for monitoring load-dependent symptoms in active individuals [12–16, 18–19].

A typical acquisition setup uses contact accelerometers or piezoelectric sensors placed over a joint and synchronized with a standardized movement task. For the knee, sensors are often placed over the patella or tibial plateau during repeated flexion–extension; for smaller joints, placement is adapted to anatomy. For the chest wall, analogous recordings can be performed near the SCJ, parasternal region, or costal margin, but robust validation for these applications remains limited. Standardization of sensor placement, sampling rate, filtering, and movement cadence is essential because small methodological differences can substantially change measured features.

Signal Processing and Feature Extraction

Most pipelines include preprocessing (noise reduction, band-pass filtering, artifact rejection), segmentation of movement cycles, and extraction of time-domain and frequency-domain features. Common metrics include root-mean-square amplitude, peak amplitude, energy, spectral centroid, dominant frequency bands, entropy measures, and burst counts. Advanced approaches incorporate time–frequency representations (wavelets, empirical mode decomposition) and non-linear metrics to improve robustness, particularly when signals are non-stationary and contaminated by movement artifacts.

Machine learning models have been used to classify joint status (e.g., healthy versus degenerative) or to differentiate movement patterns, typically with supervised algorithms trained on labeled datasets. While reported accuracies can be high, performance often declines when acquisition conditions differ from the training set or when sample sizes are small. Transparent reporting, external validation, and clinically meaningful endpoints are therefore essential before AE/VAG can be considered a diagnostic tool rather than a research measurement.

Clinical Applications and Current Evidence

In peripheral joints, AE/VAG has been explored as a non-invasive adjunct for detecting functional alterations associated with cartilage degeneration, synovitis, and altered joint congruence, especially in the knee [12–16, 18–19]. Many studies suggest that joints with degenerative changes exhibit higher signal energy and altered spectral distributions during standardized tasks. However, overlap between symptomatic and asymptomatic individuals is common, and the relationship between acoustic features and patient-important outcomes (pain, function, sport performance) remains insufficiently characterized.

For the sternum and chest wall, objective acoustic assessment is at an early stage. The heterogeneous anatomy and the influence of respiration, posture, and sensor placement introduce additional noise sources. Nevertheless, the same conceptual framework standardized provocation tasks, synchronized kinematics, and robust processing could enable future studies to differentiate benign cavitation events from clinically relevant snapping due to instability or slipping rib phenomena. Such work would be particularly valuable for monitoring rehabilitation progress and for validating conservative versus interventional management pathways.

Practical Considerations for Translation to Practice

At present, AE/VAG should be viewed as a complementary measurement rather than a stand-alone diagnostic test. For clinicians, the immediate value may lie in structured monitoring: repeated measurements under standardized tasks may help quantify improvement in movement quality or symptom provocation over time. For researchers, priorities include consensus terminology for sound phenotypes, protocol harmonization across devices and sites, reporting of reliability and minimal detectable change, and linkage of acoustic features to imaging findings and functional outcomes. Without these steps, the risk is premature clinical adoption that increases testing without improving decision-making.

Clinical Interpretation and Practical Implications

Across both streams, the key clinical message is that an audible sound alone does not imply pathology. Clinical relevance depends on accompanying symptoms (pain, swelling, instability, limitation), symptom trajectory, and the relationship to training load and movement context [1, 4, 6, 16, 22]. A practical assessment framework should therefore emphasize: (1) screening for red flags and urgent conditions; (2) structured functional assessment; and (3) evaluation of recent training changes, technique, and load management. Within this framework, acoustical methods may serve as adjunctive tools for longitudinal monitoring and hypothesis-driven assessment, rather than as standalone diagnostic tests [14–16, 18–19].

Assessment Framework

Clinical assessment should begin with targeted triage. First, identify red flags and determine whether the primary complaint is sound, pain, or functional limitation. Second, clarify the time course (acute, recurrent, chronic) and the movement context (load, speed, range, fatigue). For peripheral joints, history should address trauma, swelling, locking, giving way, and symptom evolution. For chest wall complaints, clinicians should confirm that cardiopulmonary causes have been appropriately considered and document systemic symptoms, inflammatory features, and focal bony tenderness.

Examination should attempt to reproduce symptoms under controlled conditions. This often includes active and passive range of motion, resisted testing, and functional tasks that mirror sport-specific loads. For sternal/chest wall symptoms, provocative maneuvers can include shoulder protraction/retraction, horizontal adduction, overhead elevation, trunk rotation, deep breathing, cough simulation, and palpation of the SCJ, parasternal junctions, and costal margin. Mapping the most tender and most provocative site improves diagnostic precision and helps tailor rehabilitation.

Practical Management Strategies

When sound is isolated and painless, management is primarily reassurance and education. Athletes can be advised that painless cracking is common, often physiological, and not a reliable marker of tissue damage. The emphasis should be on maintaining participation and on monitoring for red flags rather than on avoiding a harmless sound.

When sound is accompanied by pain, initial management typically involves temporary modification of provoking movements, reduction of training volume or intensity, and short-term symptom control. Rehabilitation should target movement quality, local tissue capacity, and kinetic-chain contributors. For chest wall symptoms this commonly includes thoracic mobility, scapular control, graded pressing progressions, trunk stability, and breathing mechanics. For suspected slipping rib phenomena, trunk control and avoidance of high-irritation rotational or crunch-type loads can be useful early strategies.

Manual therapy may provide short-term symptom relief in selected cases—particularly when thoracic mobility restrictions or rib dysfunction contribute to symptoms—but it should be embedded within an active rehabilitation plan rather than used as a stand-alone intervention. For persistent costochondral pain, topical or oral anti-inflammatories and structured stretching programs may be considered; refractory cases require re-evaluation to exclude alternative diagnoses and, in appropriate contexts, referral [28].

Return-to-Training and Load Progression

A graded return-to-training strategy reduces recurrence and builds confidence. Progression should be guided by pain response during and after training (including a 24-hour response), restoration of full range of motion, and performance metrics relevant to the sport. For chest wall symptoms, progression can move from low-load scapular and thoracic control work to submaximal pressing and then to sport-specific patterns (dips, rings, overhead lifts), ensuring that symptoms do not escalate with increasing intensity.

If symptoms persist beyond expected time frames, worsen despite load modification, or are associated with instability or neurological symptoms, imaging or specialist input is appropriate. In suspected SRS with severe or recurrent pain and reproducible slipping sensations, dynamic ultrasound may support diagnosis and guide referral decisions; in refractory cases, surgical consultation can be considered after an adequate trial of conservative care [27].

Communication and Shared Decision-Making

Clear communication is central. Patients benefit from an explicit explanation that "sound alone is not a diagnosis" and that decisions are based on the combination of history, examination, and targeted testing when required. Providing a simple framework reassure and monitor versus modify load and rehabilitate versus investigate and refer reduces uncertainty and improves adherence. Shared decision-making should incorporate sport demands, athlete goals, symptom tolerance, and risk profile, with a plan for follow-up if symptoms change.

Limitations and Future Directions

Current evidence is limited by heterogeneity in definitions (e.g., cracking vs clicking vs crepitus; sternal cracking vs snapping), variable outcome measures, and a predominance of observational designs—particularly in the sternal/chest wall literature where case reports and small series are common [2–11, 17]. For AE/VAG, the absence of consensus protocols, standardized tasks, and clinically meaningful thresholds remains a major barrier [12, 14–15]. Future work should prioritize harmonized acquisition/analysis pipelines, transparent reporting standards, and prospective studies linking acoustical biomarkers to clinically relevant outcomes, including early detection of functional impairment and response to load modification or rehabilitation [12–16, 18–19].

Additional limitations arise from the scarcity of prospective data in athletic populations. Much of the literature on sternal/chest wall cracking is descriptive, and even within slipping rib syndrome the epidemiology remains uncertain because the condition is frequently under-recognized and diagnosis is delayed [3, 25–26]. In peripheral joints, AE/VAG studies are often cross-sectional and rely on surrogate markers rather than clinical outcomes.

Objective acoustic methods face practical challenges: acquisition is sensitive to sensor placement, movement cadence, soft-tissue artifact, and environmental noise. Many studies report promising classification performance, but external validation across devices, sites, and patient populations is uncommon, and clinically meaningful thresholds (minimal detectable change, predictive value for outcomes) are rarely established [14–16, 18–19].

Future research priorities include consensus terminology for sound phenotypes, standardized protocols for both patient-reported and recorded sounds, and prospective cohorts that link sound patterns to symptoms, function, and imaging outcomes over time. For the chest wall, validation of dynamic ultrasound protocols and evaluation of conservative rehabilitation programs versus interventional pathways are high-value targets [27].

From a translational perspective, integrating wearable sensors with kinematic monitoring could enable ecologically valid assessment during training. Adoption should be contingent on rigorous validation and clear clinical use-cases (screening, monitoring, or outcome assessment) rather than novelty alone.

Conclusions

Sternal cracking warrants clinical vigilance. After urgent conditions and cardiopulmonary causes have been excluded, common musculoskeletal explanations include sternoclavicular joint (SCJ) disorders and slipping rib syndrome. In the context of trauma or suspected overload/stress injury, imaging and cause-directed management should be considered, alongside training-load modification when relevant [2–11].

Advances in acoustic emission (AE) recording and vibroarthrography (VAG), supported by modern signal analysis and machine learning, suggest potential for noninvasive acoustical biomarkers of knee joint function, including early differentiation of pre-radiographic states. However, routine clinical implementation requires standardized acquisition protocols, harmonized feature sets, and robust prospective validation in clinically representative populations [12–16, 18–19].

Based on recent (2023–2025) and foundational literature, joint sounds in physically active individuals are common and are usually physiological, particularly when not accompanied by pain, swelling, instability, or functional limitation. Accordingly, isolated audible sounds should be interpreted within the broader clinical picture, with clinical relevance driven by symptom context, symptom dynamics, and the relationship to training load rather than by the presence of sound alone [1, 16, 22–23].

In physically active individuals, the central clinical task is to contextualize the symptom. Isolated, painless cracking is usually physiological and does not require treatment. Repetitive snapping or clicking should be interpreted in relation to the movement that provokes it, the presence of pain, and any functional limitation. For anterior chest wall complaints, a structured pathway that first excludes cardiopulmonary disease and then considers musculoskeletal sources—particularly SCJ dysfunction, costochondral irritation, and slipping rib syndrome—is pragmatic and evidence-consistent [3, 25–28].

Objective acoustic approaches (AE/VAG) represent a promising research direction. Their near-term potential lies in standardized monitoring and mechanistic studies linking symptoms to measurable changes in movement and tissue interactions. Routine clinical use should await protocol harmonization, external validation, and demonstration that acoustic biomarkers improve diagnostic accuracy or patient-important outcomes beyond standard clinical assessment [14–16, 18–19].

Supplementary Materials

Not applicable.

Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Kechris C, Thevenot J, Teijeiro T, Stadelmann VA, Maffiuletti NA, Atienza D. Acoustical features as knee health biomarkers: A critical analysis. Artif Intell Med. 2024;158:103013. https://doi.org/10.1016/j.artmed.2024.103013
2. Ciatti C, Masoni V, Maniscalco P, Asti C, Puma Pagliarello C, Caggiari G, et al. Management Options for Traumatic Posterior Sternoclavicular Joint Dislocation: A Narrative Review with a Single Institution's Experience. J Clin Med. 2024;13(18):5428. https://doi.org/10.3390/jcm13185428
3. Madeka I, Alaparthi S, Moreta M, Peterson S, Mojica JJ, Roedl J, et al. A Review of Slipping Rib Syndrome: Diagnostic and Treatment Updates to a Rare and Challenging Problem. J Clin Med. 2023;12(24):7671. https://doi.org/10.3390/jcm12247671

4. Hansen AJ, Hayanga JWA, Toker A, Badhwar V. Costal margin reconstruction for slipping rib syndrome: Outcomes of more than 500 cases and advancements beyond earlier sutured repair technique. JTCVS Open. 2024;19:347–354. https://doi.org/10.1016/j.xjon.2024.03.007
5. Madeka I, Noueihed J, Okusanya O, et al. Diagnostic, therapeutic, and surgical repair trends in slipping rib syndrome: a survey of surgeons in the United States. J Thorac Dis. 2025;17(7):4849–4857. https://doi.org/10.21037/jtd-2025-568
6. Abou Adma H, Tran H, Holguin M, et al. An Isolated Manubrium Fracture in a Young Football Player: A Case Report. Cureus. 2025;17(3):e81336. https://doi.org/10.7759/cureus.81336
7. Fukuda Y, Kato K, Otoshi K, Hakozaki M, Kaneuchi Y, Matsumoto Y. Rib stress fracture in a female athlete caused by bouncing the barbell in bench press exercise: A case report. SAGE Open Med Case Rep. 2024;12:2050313X241232863. https://doi.org/10.1177/2050313X241232863
8. Ong CJ, Mourad O, Weiss E. Sternal stress fracture presenting as acute chest pain. Radiol Case Rep. 2023;18(12):4435–4438. https://doi.org/10.1016/j.radcr.2023.09.029
9. Gianneschi GB, Dusheiko M, DeLuca V, et al. Costal cartilage excision for slipping rib syndrome: A single-site retrospective cohort study. Int J Osteopath Med. 2025;58:100785. https://doi.org/10.1016/j.ijosm.2025.100785
10. Planchamp T, Rouch A, Verge R, Bolzinger M, et al. Secondary manubriosternal joint dislocation displacement in a teenager patient. Trauma Surg Acute Care Open. 2024;9:e001259. https://doi.org/10.1136/tsaco-2023-001259
11. Ngatchou W, Ngassa Fosso M, Guimfacq Djumegue V, Surdeanu IR, Jissendi P, Youatou Towo P. Posterior sternoclavicular joint dislocation in a young male: a case report. Pan Afr Med J. 2024;47:138. https://doi.org/10.11604/pamj.2024.47.138.28888
12. Machrowska A, Karpiński R, Krakowski P, Jonak J, Maciejewski M. Multi-Scale Analysis of Knee Joint Acoustic Signals for Cartilage Degeneration Assessment. Sensors (Basel). 2025;25(3):706. https://doi.org/10.3390/s25030706
13. Machrowska A, Karpiński R, Maciejewski M, Jonak J, Krakowski P. Application of EEMD-DFA Algorithms and ANN Classification for Detection of Knee Osteoarthritis Using Vibroarthrography. Appl Comput Sci. 2024;20(2):90–108. https://doi.org/10.35784/acs-2024-18
14. Sakib N, Khan TI, Hassan MM, Ide S. Robustness analysis of soft Gaussian mixture model clustering for acoustic emission features in characterizing osteoarthritic knees. Med Eng Phys. 2025;146:104435. https://doi.org/10.1016/j.medengphy.2025.104435
15. Richardson KL, Nichols CJ, Stegeman RG, et al. Validating Joint Acoustic Emissions Models as a Generalizable Predictor of Joint Health. IEEE Sens J. 2024;24(10):17219–17230. https://doi.org/10.1109/JSEN.2024.3382613
16. Khokhlova L, Komaris DS, O'Flynn B, Tedesco S. Correlation between proprioception, functionality, patient-reported knee condition and joint acoustic emissions. PLoS One. 2024;19(11):e0310123. https://doi.org/10.1371/journal.pone.0310123

17. Moyal AJ, Burkhart RJ, Adelstein JM, Voos JE, Apostolakos JM, Calcei JG. Acromioclavicular and sternoclavicular joint injuries in contact sports: a narrative review of conservative and surgical treatments. Ann Joint. 2025;10:31. https://doi.org/10.21037/aoj-25-19
18. Nichols CJ, Özmen GC, Richardson K, Inan OT, Ewart D. Classifying Pre-Radiographic Osteoarthritis of the Knee Using Wearable Acoustics Sensing at the Point of Care. IEEE Sens J. 2023;23(23):29619–29629. https://doi.org/10.1109/JSEN.2023.3325153
19. Goossens Q, Locsin M, Gharehbaghi S, Brito P, Moise E, Ponder LA, et al. Knee acoustic emissions as a noninvasive biomarker of inflammatory knee involvement in juvenile idiopathic arthritis. Pediatr Rheumatol Online J. 2023;21:59. https://doi.org/10.1186/s12969-023-00842-7
20. Gupta RB, Jindal M. A 20-year-old with anterior chest pain: rare diagnosis behind a common concern. Chest. 2025;168(4):e93–e98. https://doi.org/10.1016/j.chest.2025.04.024
21. Langenfeld A, Baechler M, Swanenburg J, Mühlemann M, Nyirö L, Streuli D, et al. Systematic review on biomechanical effects of high-velocity, low amplitude spinal manipulation. PLoS One. 2025;20(7):e0328048. https://doi.org/10.1371/journal.pone.0328048
22. Sillevis R, Selva-Sarzo F, Weiss V, Sanchez Romero EA. Do Audible Sounds During a Metacarpophalangeal and Metatarsophalangeal Thrust Manipulation Have an Impact on Intra-Articular Joint Space and Brainwave Activity? Healthcare (Basel). 2025;13(5):554. https://doi.org/10.3390/healthcare13050554
23. Whitman D, Sillevis R, Frommelt M. The Effect of Audible Joint Manipulation Sounds in the Upper Cervical Spine on Brain Wave and Autonomic Nervous System Activity. Life (Basel). 2025;15(1):103. https://doi.org/10.3390/life15010103
24. Kawchuk GN, Fryer J, Jaremko JL, Zeng H, Rowe L, Thompson R. Real-Time Visualization of Joint Cavitation. PLoS One. 2015;10(4):e0119470. https://doi.org/10.1371/journal.pone.0119470
25. Gress K, Charipova K, Kassem H, Berger AA, Cornett EM, Hasoon J, Schwartz R, Kaye AD, Viswanath O, Urits I. A Comprehensive Review of Slipping Rib Syndrome: Treatment and Management. Psychopharmacol Bull. 2020;50(4 Suppl 1):189–196 https://doi.org/10.64719/pb.4389
26. McMahon LE. Slipping Rib Syndrome: A review of evaluation, diagnosis and treatment. Semin Pediatr Surg. 2018;27(3):183–188. https://doi.org/10.1053/j.sempedsurg.2018.05.009
27. Schultz N, Qubain L, Riemann M, Temkit M, McMahon LE, Van Tassel D. Dynamic ultrasound evaluation of patients with suspected slipping rib syndrome: five years in. Skeletal Radiol. 2025;54(12):2777–2786. https://doi.org/10.1007/s00256-025-04961-y
28. Schumann JA, Sood T, Parente JJ. Costochondritis. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Last Update: April 20, 2024. Available from: https://www.ncbi.nlm.nih.gov/books/NBK532931/

29. Basavaraju KS, Kishore Kumar T. Vibroarthrographic Signal Classification for Knee Joint Disorder Detection using Tunable Q-factor Wavelet Transform based on Entropy Measures. Eng Technol Appl Sci Res. 2025;15(1):19953–19958. https://doi.org/10.48084/etasr.9245
30. Karpiński R, Prus A, Jonak K, Krakowski P. Vibroarthrography as a Noninvasive Screening Method for Early Diagnosis of Knee Osteoarthritis: A Review of Current Research. Appl Sci (Basel). 2025;15(1):279. https://doi.org/10.3390/app15010279