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SCIENTIFIC ARTICLE

Dynamic ultrasound in the evaluation of patients with suspected slipping rib syndrome

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Abstract

Objective Slipping rib syndrome (SRS) affects adolescents and young adults. Dynamic ultrasound plays a potential and likely significant role; however, limited data exist describing the protocol and techniques available. It is our intent to describe the development of a reproducible protocol for imaging in patients with SRS.

Materials and Methods Retrospective review of suspected SRS patients from March 2017 to April 2018. A total of 46 patients were evaluated. Focused history and imaging was performed at the site of pain. Images of the ribs were obtained in the parasagittal plane at rest and with dynamic maneuvers. Dynamic maneuvers included Valsalva, crunch, rib push maneuver, and any provocative movement that elicited pain. Imaging was compared with records from the pediatric surgeon specializing in slipping ribs. Statistical analysis was performed.

Results Thirty-six of the 46 patients had a diagnosis of SRS, and had an average age of 17 years. Thirty-one patients were female, 15 were male. Thirty-one out of 46 (67%) were athletes. Average BMI was 22.6. Dynamic ultrasound correctly detected SRS in 89% of patients (32 out of 36) and correctly detected the absence in 100% (10 out of 10). Push maneuver had the highest sensitivity (87%; 0.70, 0.96) followed by morphology (68%; 0.51, 0.81) and crunch maneuver (54%; 0.37, 0.71). Valsalva was the least sensitive (13%; 0.04, 0.29).

Conclusion Dynamic ultrasound of the ribs, particularly with crunch and push maneuvers, is an effective and reproducible tool for diagnosing SRS. Valsalva plays a limited role. In addition to diagnosing SRS, ultrasound can give the surgeon morphological data and information on additional ribs at risk, thereby assisting in surgical planning.

Keywords Slipping rib syndrome · Chest pain · Rib pain · Abdominal pain · Dynamic ultrasound

Introduction

Slipping rib Syndrome (SRS) is a condition that affects children, adolescents, and adults of any age, with a predilection for females. It is often an overlooked cause of upper abdominal and lower chest wall pain. SRS is described as hypermobility of the anterior false ribs, either from disruption of fibrous articulation, or a congenital/developmental deformity that allows for the edges of the 8th to 10th ribs to slip, click, or pop as the cartilaginous rib tip comes in close proximity or actually slips under the rib above (Fig. 1) [1, 2]. Additionally, a variant lack of cartilaginous attachments of the true 6th and 7th ribs to the sternum may predispose to slipping at these levels as well [3]. Pain occurs from impingement of the intercostal nerve along the undersurface of the adjacent rib with movements such as twisting, bending, deep breathing, sneezing, or coughing. The resulting irritation to the intercostal nerves may cause intermittent sharp/stabbing pains or a constant dull aching pain or burning sensation. Some patients describe temporary relief by stretching the affected side or placing pressure on the area. Prolonged periods of rest are often required to alleviate the pain; however, pain often returns when activity increases. The true prevalence of SRS is unknown owing to frequent under-diagnosis [4].

In early 2016, our department began receiving requests from our pediatric surgeons to evaluate for SRS. The pediatric surgery group at our institution is well versed in pathological

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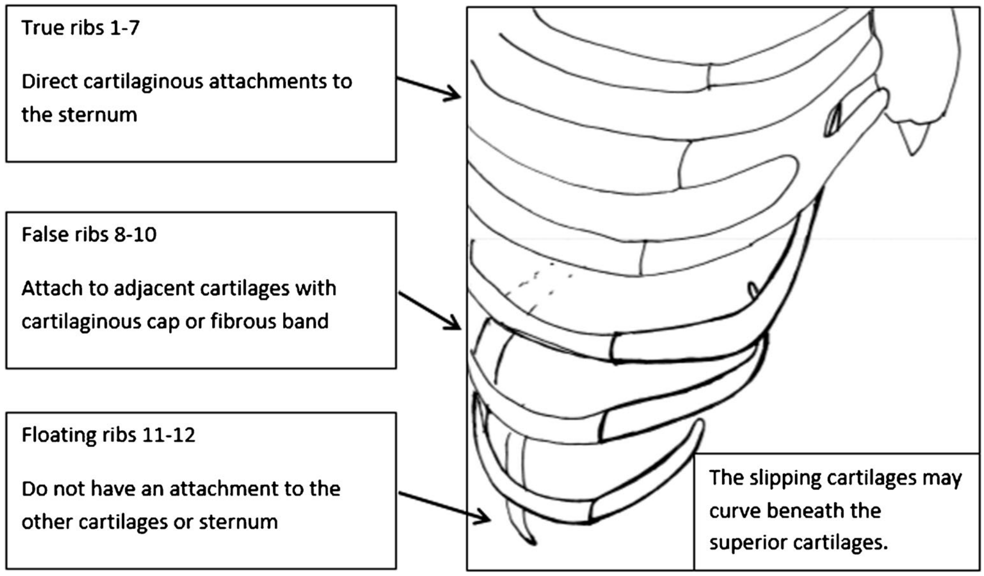

Fig. 1 Differentiation of rib classifications with illustration of abnormal rib morphology predisposing to symptomatic slipping rib

conditions of the chest wall and was becoming more specialized in treating patients from all over the country with SRS. After discussing dynamic ultrasound with our surgeons, we attempted to create a reproducible protocol that would improve the sensitivity, specificity, and accuracy of diagnosing SRS.

It is the intent of this article to describe the development and analysis of an effective and reproducible protocol for dynamic imaging in patients with SRS. With such a protocol, we intend to improve disease recognition, reproducibility, and appropriate diagnosis in this patient population.

Materials and methods

Overview

Patients were scanned in the ultrasound department preceding or following clinical consultation with the pediatric surgeon. Imaging was initially performed by the lead sonographer of the department who has 29 years of experience. Once an established protocol and worksheet were created, additional staff members were cross-trained. The level of experience ranged from 5 to 25 years. A majority of patients were evaluated using ultrasound prior to their surgical consultation appointment. Patients who were seen by the surgeon before ultrasound were scanned ahead of chart review. After a focused history was taken detailing the location of the patient's symptoms, and the motions and maneuvers that elicited pain, we obtained cine clips of the bilateral ribs in the short axis plane at rest and with dynamic maneuvers. Special attention was given to the pinpointed pain site. Both the surgeons and the radiologists involved in the workup and diagnosis of SRS clinically and radiographically had prior experience with treating and/or interpreting SRS patients. Notably, the lead surgeon specializes in SRS, often seeing and treating patients from around the world.

Scanning

Patients were evaluated by Philips scanners (Philips IU-22 and EPIQ7) utilizing a high frequency 12−5 linear transducer with a musculoskeletal preset. Patients were positioned supine on the examination bed in a comfortable position, most often with the head of the bed flat. Ribs were numbered by counting from the bottom after identifying the 12th rib at the T12 vertebral body. In unclear cases where morphology was abnormal, or in cases where it was suspected that there were only 11 ribs, numbering was confirmed by identification of the last rib attached to the sternum (the 7th rib) and counting down from the top. Cine clip images were obtained at rest by beginning at the ossified portion of the rib in the short axis and scanning medially along the course of each rib to its cartilaginous tip (Fig. 2). Despite occasional areas of cartilaginous fusion/cartilaginous bridging, the rib cartilage was imaged to the tip. This was performed bilaterally for ribs 6–10. Evaluation of each ribs' morphology included the presence or absence of fusion to the adjacent superior rib, any cartilaginous bars/bridges between ribs, and any hooked or dysmorphic appearance of the rib tips. Additionally, the morphology and echogenicity of the surrounding intercostal soft tissues were evaluated (Figs. 2, 3).

Dynamic maneuvers were performed by locating the cartilaginous tip of each rib and demonstrating it in the short axis adjacent to the rib above it. The respective maneuver was then performed while imaging cine clips with the probe in a fixed position at the rib tip. Valsalva maneuver, the first of three dynamic maneuvers, was

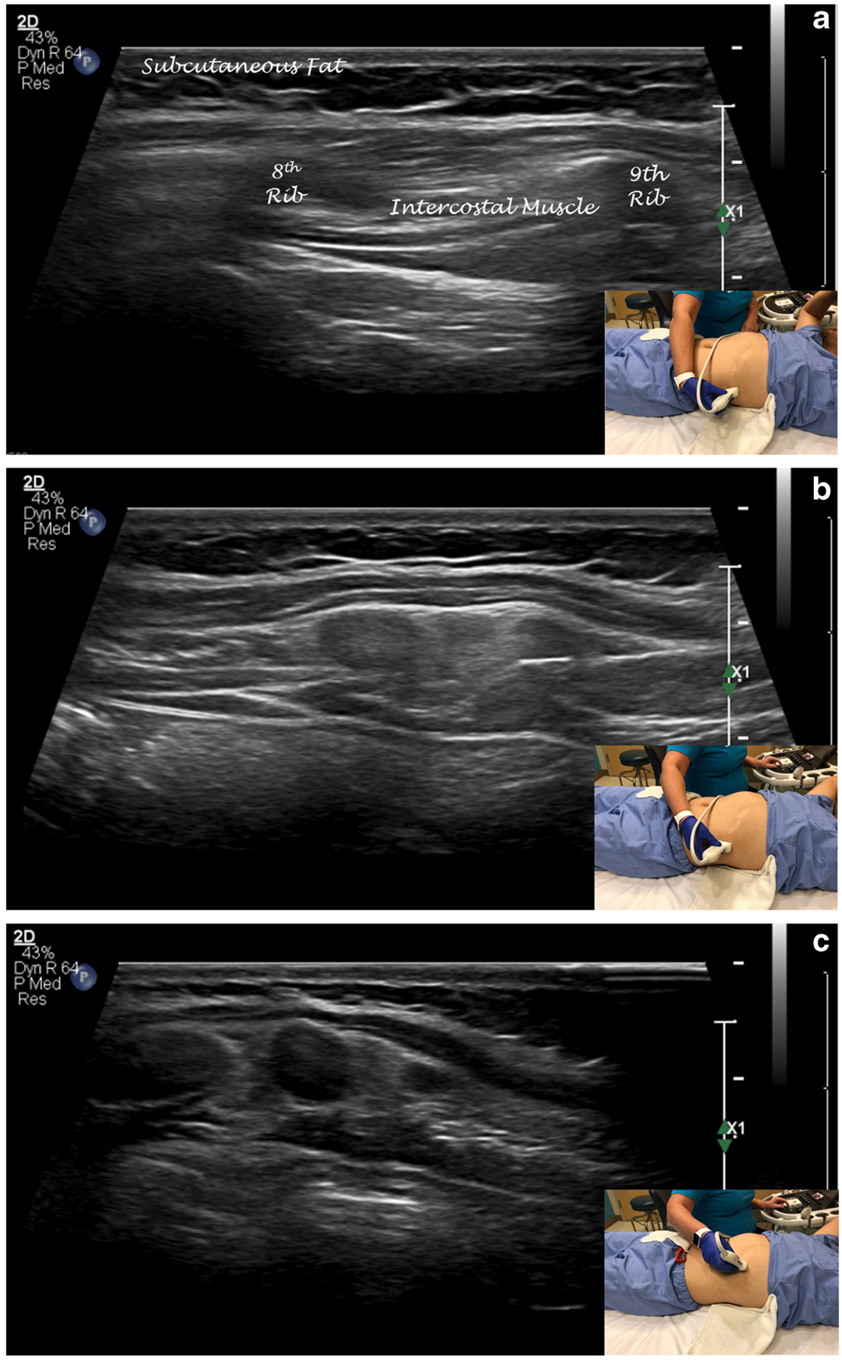

Fig. 2 **a**–**c** Scanning rib morphology with the transducer placed transverse in the location of the ossified rib and scanning medially toward the cartilaginous rib tip

performed by asking the patient to bear down (Figs. 4, 5). Second, the crunch maneuver was performed by asking the patient to raise their head only very slowly and to contract their abdominal muscles (Figs. 6, 7). Raising the shoulders as part of the maneuver led to too much motion and made it too difficult to image simultaneously. Last, the rib push maneuver was performed by the radiologist by placing either the thumb or the paired middle and index fingers just below the rib tip of interest (Fig. 8). The radiologist then used graded pressure in a deep and upward motion to try to demonstrate laxity and displacement of the rib of interest deep to, and underneath, the adjacent rib while scanning (Fig. 9). Although similar to the clinical hook maneuver, the push maneuver does not retract the subluxing rib against the adjacent level, as the rib reduces back to a resting position. Finally, any movement described by the patient as being a characteristic motion that would elicit clicking, popping, or pain would be

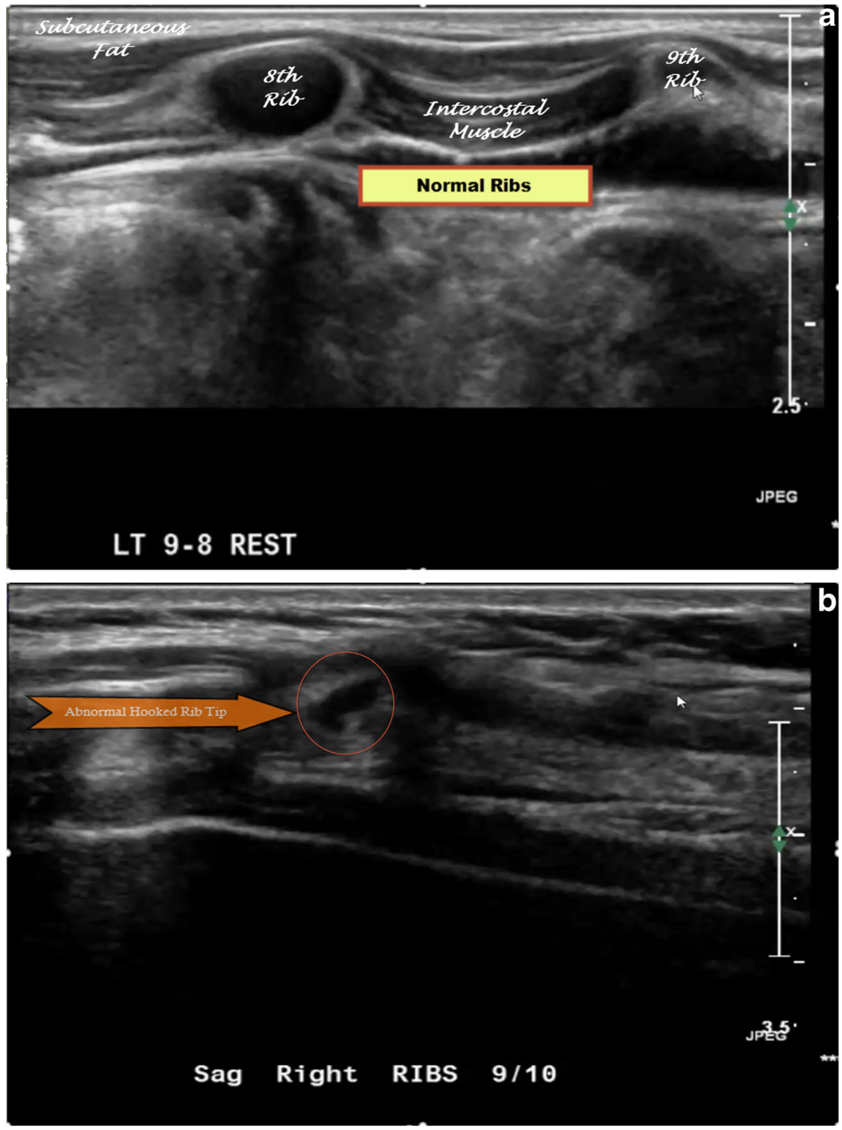

Fig. 3 **a** Normal cartilage morphology of the 8th and 9th ribs with normal intercostal musculature and subcutaneous soft tissues. **b** Abnormal cartilage morphology with hooked hypoechoic cartilaginous rib tip

Fig. 4 Scanning of the rib cartilage while performing Valsalva maneuver

performed while the probe was fixed in a position at the cartilaginous tip of the rib of interest. Dynamic maneuvers were performed at each individual rib level.

Data collection

A retrospective review was performed of prospectively collected data from suspected SRS patients who presented either to the Radiology or the Surgery department from March 2017 through April 2018.

Demographic data were collected, including patient's age, gender, activity/sport performance, and BMI. The laterality of slipping rib and hand dominance were not recorded data points.

Retrospective analysis of the ultrasound findings was performed by the lead musculoskeletal radiologist experienced

Fig. 5 **a** Valsalva maneuver at rest with normal intercostal musculature. **b** Abnormal Valsalva with impingement and displacement of the intercostal musculature

with SRS. The images were evaluated blindly to assess for sonographic findings suggestive of SRS, including abnormal morphology of the cartilaginous rib tips, derangements of the surrounding intercostal soft tissues, or abnormal motion of the ribs during dynamic maneuvers.

Fig. 6 Scanning of the rib cartilage while performing the crunch maneuver

Surgeon clinical examination and surgical reports were evaluated alongside the dynamic imaging examination. Data collected included the presence or absence of slipping ribs on physical examination and any pertinent intraoperative findings, the gold standard reference being the clinical physical examination, including the hook maneuver (Fig. 10). The final SRS diagnosis was made based on clinician judgment by the surgeon.

Statistics

Group comparisons were conducted using the Wilcoxon rank sum test for continuous variables and Fisher's exact test for categorical variables. Estimates of sensitivity and specificity

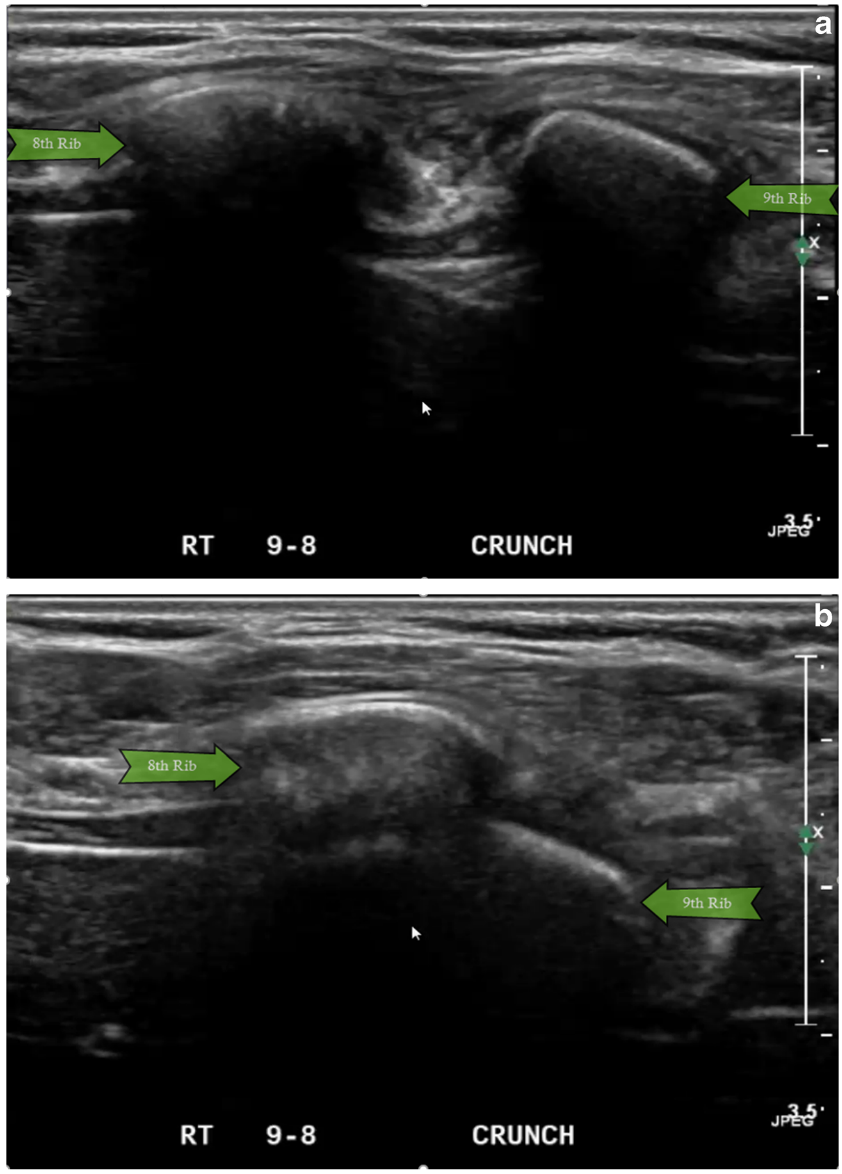

Fig. 7 **a** The 8th and 9th ribs at rest before the crunch maneuver. Note that the ribs are level and are not abutting one another. **b** The 8th and 9th ribs during the crunch maneuver with the 9th rib moving deep to, and abutting, the adjacent 8th rib

Fig. 8 Push maneuver scanning position and thumb placement relative to the transducer

were provided, along with the 95% confidence interval (CI) based on the binomial distribution and exact confidence limits.

Results

Forty-six patients were imaged during the study period, and 36 patients received a clinical diagnosis of SRS. Some patients underwent imaging more than once (either as a follow-up for planning before surgery or for recurrent/new symptoms following surgery) for a total of 57 ultrasound examinations. Of the patients declared negative for SRS, one patient was lost to follow-up, whereas the remainder of the patients were diagnosed with a variety of etiologies, including costochondritis,

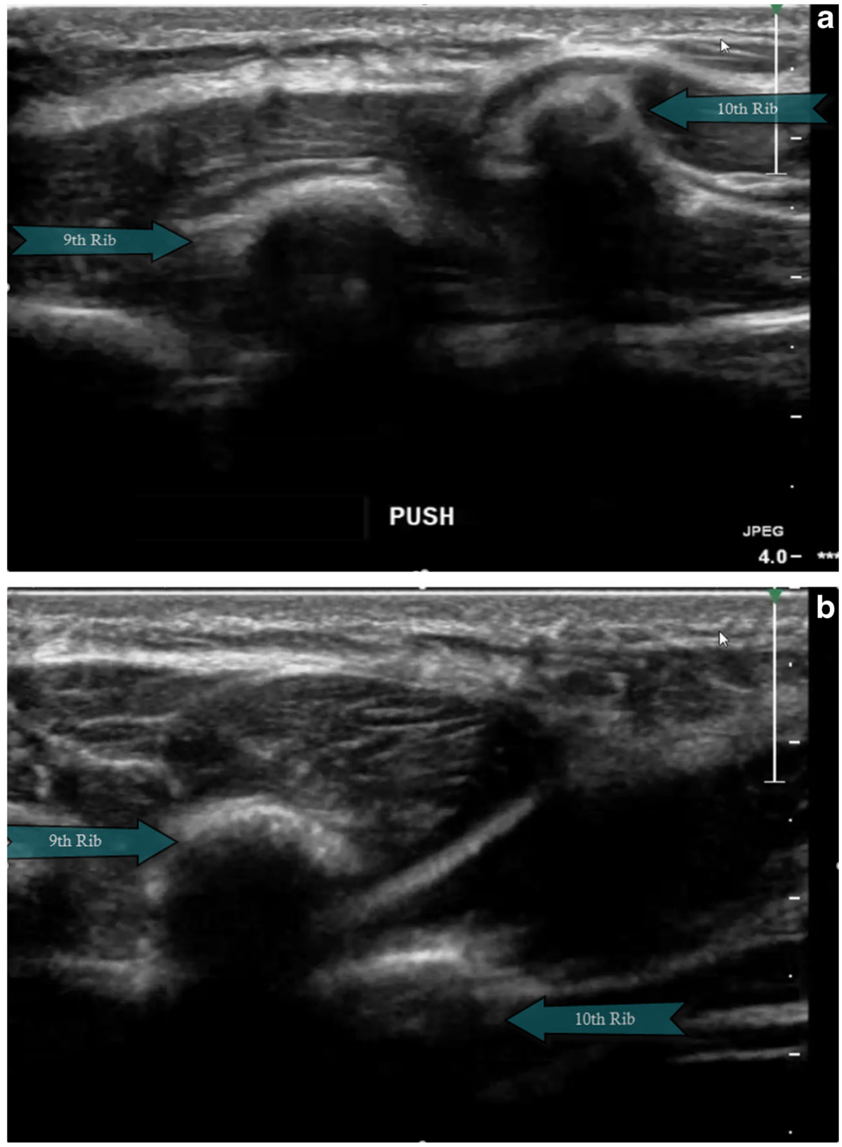

Fig. 9 **a** The 9th and 10th ribs at rest before the push maneuver. Note that the 10th rib is slightly anterior to the 9th rib, with a narrow intercostal space. **b** The 9th and 10th ribs during the push maneuver. Note that the 10th rib is displaced deep to and underneath the 9th rib, with obliteration of the intercostal space

snapping scapula, cholelithiasis, and complex pain secondary to umbilical hernia.

Fig. 10 The hook maneuver performed with the patient under anesthesia in the operating room

Sixty-seven percent of the patients (31) were female, whereas 33% (15) were male. The average BMI was 22.6, with an average age of 17 years. Sixty-seven percent of our patients (31) were athletes, the most common sports being swimming and softball, followed by running, soccer, volleyball, weightlifting, band, etc. No significant difference was present between demographics of patients with SRS and without SRS (Table 1).

Utilizing the clinical examination diagnosis of SRS via the hooking maneuver, or surgical confirmation of slipping rib, dynamic ultrasound correctly detected SRS in 89% (32 out of 36) of patients and found no evidence of SRS in 100% (10 out of 10) of cases. The rib push maneuver had the highest sensitivity at 87% (0.70, 0.96) followed by morphology at 68% (0.51, 0.81), and crunch maneuver at 54% (0.37, 0.71). Valsalva was the least sensitive at 13% (0.04, 0.29; Table 2).

Table 1 Demographics and diagnostic modalities by slipping rib

	No ($n = 16$)	Yes ($n = 41$)	Total ($n = 57$)	p value
Age				0.4269[a]
n	16	41	57	
Mean (SD)	15.6 (3.3)	17.6 (5.0)	17.1 (4.6)	
Median	16.0	16.0	16.0	
Q1, Q3	14.5, 18.0	15.0, 23.0	15.0, 19.0	
Range	(6.0–19.0)	(8.0–27.0)	(6.0–27.0)	
Gender *n* (%)				0.7529[b]
Female	12 (75.0)	28 (68.3)	40 (70.2)	
Male	4 (25.0)	13 (31.7)	17 (29.8)	
Sport/activity *n* (%)				0.5818[b]
Missing	6 (31.6)	13 (68.4)	19	
Marching Band	0 (0.0)	1 (3.6)	1 (2.6)	
Cross-country runner	0 (0.0)	1 (3.6)	1 (2.6)	
Lacrosse	1 (10.0)	0 (0.0)	1 (2.6)	
Runner	0 (0.0)	1 (3.6)	1 (2.6)	
Snowboarding accident	0 (0.0)	1 (3.6)	1 (2.6)	
Soccer	0 (0.0)	2 (7.1)	2 (5.3)	
Weight-lifting	0 (0.0)	2 (7.1)	2 (5.3)	
Army training	0 (0.0)	1 (3.6)	1 (2.6)	
Basketball	1 (10.0)	0 (0.0)	1 (2.6)	
Dancing	0 (0.0)	1 (3.6)	1 (2.6)	
Football	1 (10.0)	0 (0.0)	1 (2.6)	
Gymnastics	0 (0.0)	2 (7.1)	2 (5.3)	
Horseback-riding	0 (0.0)	1 (3.6)	1 (2.6)	
No activity, wheelchair-bound	1 (10.0)	0 (0.0)	1 (2.6)	
Rock climbing	0 (0.0)	1 (3.6)	1 (2.6)	
Softball	3 (30.0)	1 (3.6)	4 (10.5)	
Swimming	1 (10.0)	2 (7.1)	3 (7.9)	
Trauma	1 (10.0)	1 (3.6)	2 (5.3)	
Unknown	1 (10.0)	1 (3.6)	2 (5.3)	
Volleyball	0 (0.0)	2 (7.1)	2 (5.3)	
Baseball	0 (0.0)	1 (3.6)	1 (2.6)	
Wrestling	0 (0.0)	1 (3.6)	1 (2.6)	

[a] Wilcoxon rank sum test

[b] Fisher's exact test

Fifty-two percent of patients (24) underwent surgery as part of their treatment for SRS. Of these patients, 58% (14) showed improvement in their symptoms. Seventeen percent (4) experienced continued pain, either at the same location, or at different locations following surgery. Pain was described as similar or identical to the initial presenting symptoms. No predictive physical examination or diagnostic findings were identified that would suggest surgical failure or recurrence. In patients who continued to have pain following initial surgical intervention, ultrasound was utilized to confirm rib mobility and slippage in 2 patients. One patient was found to have recurrent SRS, both by physical examination and by ultrasound, at the area of initial slippage, and the other patient had new findings at a level adjacent to the location of the initial symptoms. The remaining patients had post-surgical scarring or inflammatory changes that were attributed to their continued pain. Six patients (25%) either did not follow-up locally or followed up with surgeons at their home institutions and information was not available regarding symptoms after surgery.

Discussion

First described by Cyriax in 1919, SRS was introduced as a disease process that should be considered in patients with pain

Table 2 Diagnostic tests by slipping rib

	Slipping rib		Sensitivity (95% CI)	Specificity (95% CI)
	Present	Absent		
Morphology				
Normal	14 (87.5)	14 (34.1)		
Abnormal	2 (12.5)	27 (65.9)	0.68 (0.51, 0.81)	0.88 (0.64, 0.99)
Valsalva				
Normal	8 (100.0)	28 (87.9)		
Abnormal	0 (0.0)	4 (12.1)	0.13 (0.04, 0.29)	1.0 (0.63, 1)
Crunch				
Normal	12 (91.7)	17 (47.4)		
Abnormal	1 (8.3)	20 (52.6)	0.54 (0.37, 0.71)	0.92 (0.64, 1)
Push				
Normal	10 (81.8)	4 (15.6)		
Abnormal	2 (18.2)	27 (84.4)	0.87 (0.70, 0.96)	0.83 (0.52, 0.98)

thought to be referred secondary to a visceral process [5]. Treatment for this syndrome with costal cartilage resection was first performed in 1922 by Davies-Colley [6]. Although well received in the literature initially, little notice was taken, and its presence in the surgical and radiological textbooks is lacking. To date, almost 400 cases have been reported in the literature; yet, this diagnosis still remains obscure to most physicians.

Given cross-over in the innervation of the intercostal nerves and visceral sympathetic nerves at the spinal cord, symptoms of SRS may also be vague and misinterpreted as abdominal pain [7–10]. This can cause pain that may be associated with nausea and vomiting when severe [11–14]. The combination of atypical pain and the scarcity of medical experience with SRS can be confusing for medical practitioners, leading many patients to undergo unnecessary testing and procedures to try to identify the source of the pain. The lack of findings for the cause of pain is frustrating for physicians and patients alike [13, 15, 16].

The differential diagnosis of SRS is long and includes chest wall issues such as rib fracture, muscle strain, pleuritic pain, and costochondritis. Pathological abdominal conditions, such as gastroesophageal reflux, biliary disease, peptic ulcer, renal colic, and pancreatitis, may also be entertained.

Classically, SRS is diagnosed on physical examination utilizing the Hook maneuver where fingers are placed under the costal margin and then pulled up to displace the mobile rib anteriorly and upward (Fig. 10). Palpating the lower costal cartilage may also elicit point tenderness and movement of the slipping ribs. Up to now, imaging has played virtually no role in the evaluation and diagnosis of SRS. Currently, the literature is somewhat sparse regarding the evaluation of SRS with any imaging modality. Static imaging with radiographs, CT, and MRI may demonstrate grossly abnormal or irregular false ribs, and may reveal a lack of attachment to the adjacent rib levels; however, there is no literature describing any successful utilization of these modalities in the diagnosis of SRS. The most promising area of diagnostic imaging comes from ultrasound, with a few case studies describing patients with SRS evaluated by ultrasound. These patients had symptoms that were reproduced on ultrasound during performance of Valsalva maneuver and contraction of the abdominal musculature [17, 18]. As a center that sees a high volume of patients with this syndrome, our goal was to develop a reproducible ultrasound protocol that may aid in the diagnosis and increased awareness of this entity.

Patients with SRS may have an underlying congenital and/or developmental predisposition to impingement of the intercostal soft tissues and the neurovascular bundle owing to a lack of fusion of the false ribs. In addition, these patients may have morphological irregularities of the distal rib cartilage, with areas of hooking, nodularity, or abnormal bridging that may place them at an increased baseline risk.

Despite small numbers in the early literature suggesting the utilization of Valsalva as a valuable dynamic modality in evaluating slipping rib, our experience found Valsalva to be the least beneficial and revealing maneuver in our armamentarium. In fact, because of the timing of implementation of protocol changes early in the course of the study, early examinations included only the Valsalva maneuver. It was during this early study period that most of our false-negative examinations were performed. After discovering poor correlation in patients with clinically diagnosed SRS in this early series, it was determined that modification to our imaging protocol was necessary. In examining the possible motions and mechanisms that could lead to impingement of the intercostal soft tissues, it was decided that an active maneuver, utilizing the crunch motion, and a passive maneuver, utilizing the rib push maneuver, would best evaluate and diagnose SRS with the use of ultrasound.

In our population, patients were predominantly female, adolescent, and athletes (female:male, 4:1). Our findings are consistent with those of other large sample sized studies in the literature, which reports that female patients, and those who are athletes in particular, are more frequently affected than male patients [1, 19, 20]. This may possibly be related to hormonal shifts and joint laxity [21]. The underlying increased laxity, coupled with the increased movement in athletic patients, may place younger athletic female patients at an increased risk for rib motion and friction in the setting of congenital or acquired unfused ribs or hooking. Multiple reports of SRS occur in athletes, especially in swimmers, indicating that this group is at risk for SRS and SRS is likely because of the higher demands placed on their bodies [4, 22].

Two novel findings that were discovered during our experience with this patient population were the common occurrences of fused cartilage levels immediately above the symptomatic level, and the presence of increased intercostal soft-tissue echogenicity at the symptomatic level. Although cartilaginous fusion between levels is inherently protective against motion at the level of fusion, it provides a rigid backstop for adjacent levels, which increases the compensatory mobility at those adjacent levels. Similar to fused vertebra, the level above and below an area of fusion are often those that show sequelae of increased motion [23]. The presence of increased intercostal echogenicity, identified at many symptomatic levels, likely represents sonographic sequelae of inflammation, edema, and possibly fibrosis within the intercostal muscle and fat, similar to that of inflammation in other parts of the body [24]. These two findings, in conjunction with the dynamic mobility of the ribs during the crunch or push provocative maneuvers were most consistently diagnostic of symptomatic SRS.

During the course of the study, some patients demonstrated additional asymptomatic levels of abnormal morphology, cartilaginous fusion, or increased motion with provocative maneuvers, commonly involving the contralateral ribs at the same level. These asymptomatic levels lacked hyperechoic inflammatory changes of the surrounding intercostal soft tissues. These are believed to represent at-risk levels with an abnormality predisposing to the possible future development of symptomatic slipping rib.

Our experience has continued to strengthen our surgical colleagues' confidence in dynamic ultrasound as a diagnostic tool in both patients with suspected SRS and in postoperative patients with residual or recurrent symptoms that are often difficult to evaluate by physical examination. During the course of the study, ultrasound was increasingly used as a diagnostic modality in patients with both classic symptomology and atypical pain. Characteristic symptoms included focal pain near the area of slippage, which was exacerbated by increased activity and relieved with rest. This symptomatology was present in many patients positive for SRS; however, it did not specifically correlate with particular morphological or dynamic imaging findings. With continued experience, ultrasound may replace the hook maneuver as the diagnostic test of choice in this patient population.

Although these findings are extremely promising in the recognition and diagnosis of SRS in symptomatic patients, the need for more widespread evaluation and characterization of dynamic rib mobility in asymptomatic patients is necessary to further strengthen diagnostic validity. Additionally, population studies evaluating the overall prevalence of SRS in the public are needed to aid both clinicians and patients alike in the understanding of the syndrome and its predisposing factors. Limitations of our study include the nature of study design and the possibility of introduced bias. As a retrospective review of prospectively collected data, the aim of the study was to determine the diagnostic performance (reproducibility, sensitivity, and specificity) of a new imaging test, dynamic ultrasound, in the identification and characterization of patients with slipping rib disease. Occasionally, the performing radiologist was not blinded to the reference hook maneuver results; however, attempts to reduce bias were performed when possible. Specifically, in a few cases in which patients underwent imaging following initial surgical consultation, they were scanned specifically without chart review beforehand. Nevertheless, to optimize patient diagnosis and outcomes, and to perform a focused and appropriate diagnostic examination, patients were interviewed and an HPI was obtained by the performing radiologist, sometimes leading to patient disclosed outcomes of the reference hook maneuver. However, most patients underwent imaging before surgical consultation, thus avoiding the bias of reference standard results.

Conclusion

Dynamic ultrasound imaging of the ribs, particularly with utilization of crunch and rib push maneuvers, correctly detected the presence of SRS in 89% of cases and detected its absence in 100% of cases. SRS has been part of the medical and surgical literature for almost a century, and although the treatments for this syndrome are well outlined, the lack of a consistent and reproducible diagnosis may lead to improper management. Dynamic ultrasound is a useful diagnostic tool when performed properly, having the ability to provide the surgeon with morphological data, rib level involvement, and information on additional ribs that are at risk, thereby assisting with surgical planning and with patients who have recurrent pain after surgery.

Compliance with ethical standards

Disclosures This article is currently solely submitted for review as original research to Skeletal Radiology. This material is IRB approved and is the result of work supported with resources and the use of facilities at the Phoenix Children's Hospital.

Conflicts of interest The authors declare that they have no conflicts of interest.

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