Costal margin reconstruction for slipping rib syndrome: Outcomes of more than 500 cases and advancements beyond earlier sutured repair technique

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ABSTRACT

Objectives: To evaluate results of sutured repair for slipping rib syndrome (SRS), identify failure points, and discuss technique modifications to improve outcomes through costal margin reconstruction (CMR).

Methods: Patients undergoing repair of SRS between February 2019 and February 2024 at an academic referral institution were retrospectively analyzed. Pain scores, quality of life, pain medication use, and reoperations were evaluated pre- and postoperatively at 1 and 6 months. In patients failing sutured repair we identified specific failure points and devised a new CMR technique to overcome them. Subsequent CMR patients were followed at 1, 6, 12, 18, and 24 months using the same outcome measures.

Results: Four hundred forty-nine patients underwent repair. Two hundred forty-one patients underwent sutured repair with revision required in 66. Median time to revision was 14 months. CMR was developed and performed in 247 patients. In CMR patients, preoperative mean pain score of 7.5 out of 10 dropped postoperatively to 4.0, 2.5, 1.9, 1.3, and 0.9 at 1, 6, 12, 18, and 24 months, respectively ($P < .001$). Mean quality of life of 38% improved to 73%, 83%, 88%, 93%, and 95% at the same intervals ($P < .001$). Preoperatively, 29% of patients chronically used opioid medications. Opioid use dropped postoperatively to 11%, 4%, 4%, 0%, and 0% at the same intervals. Use of nonopioid medications followed a similar pattern. One CMR patient required full revision.

Conclusions: SRS is a debilitating, but correctable disorder. Improved pain and quality of life, reduction in chronic opioid use, and freedom from revision surgery suggest that CMR should be considered the standard operation for SRS. (JTCVS Open 2024;19:347-54)

Costal margin reconstruction for slipping rib syndrome.

CENTRAL MESSAGE

Costal margin reconstruction for slipping rib syndrome provides durable relief from pain and revision surgery. Patients can be freed from pain medication requirements and return to functional lives.

PERSPECTIVE

Slipping rib syndrome is a simple problem with devastating consequences for those who experience it. Long-term disability and risk of suicide can result if patients are left undiagnosed and untreated. Awareness of the disorder and education in newer reconstructive treatment options are of paramount importance to thoracic surgeons.

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Awareness of slipping rib syndrome (SRS) has grown significantly over the recent past.[1-17] It is now more readily recognized and diagnosed.[2,3,7,8,10,12,15-20] Various etiologies result in mechanical dissociation of the lower ribcage. One or more of the false ribs (ribs 8-10) that have separated from the costal margin can then collide, compressing the intervening intercostal nerves.[1-3,6-8,10,12,13,15-32] Even the most subtle of rib movements against an intercostal nerve can elicit severe, prolonged pain.

Abbreviations and Acronyms
CCE = costal cartilage excision
CMR = costal margin reconstruction
SR = sutured repair
SRS = slipping rib syndrome

The pathophysiology underlying SRS is usually described as mechanical breakdown of interchondral ligamentous connections. To our knowledge, no histologic studies of tissue from SRS patients have been conducted to prove this concept. However, we participated in 2 recent cadaveric studies[33,34] that demonstrated significant variation of costal margin anatomy compared with classic understanding. Mobility of the false rib tips was assessed in these studies. At least partial mobility was noted in the costal margin attachments of 53% of eighth ribs, 72% of ninth ribs, and 90% of 10th ribs. The 10th rib was fully floating in 52% of specimens examined. Such findings question previous anatomic understanding of the stability of the costal margin and suggest that floating 10th ribs may be a normal anatomic variant. It is currently unclear why some patients develop pain symptoms and others with subluxing ribs remain asymptomatic.

Historically, treatment strategies have not prioritized preservation and restoration of costal margin structure. Loss of false rib structure by excision has been believed to have minimal consequence. Until recently, the common surgical option employed in severe cases was costal cartilage excision (CCE) without restoring the stability of the costal margin.[2,3,7,8,10-13,15-17,19,21,25,26] There are limited published series of CCE and most accounts are small and lack clearly defined outcomes measuring success. Recurrence of pain requiring reoperation is reported in up to 30% of patients.[7,8,12,13] Due to this high reoperation rate and other shortcomings of the published approaches to SRS repair, we developed a rib-preserving, sutured repair (SR) technique with good initial results.[1] Over time, we realized limitations and specific failure points with SR. We observed considerable costal margin anatomic variability[33,34] among patients that necessitated a different strategy than simply suturing the slipped ribs back to the costal margin. Mechanisms of failure were observed and basic tenets necessary for successful outcomes identified. A new technique of costal margin reconstruction (CMR) was developed to specifically address the failure points and provide successful outcomes utilizing the tenets identified in failed cases of SR. In this article, we discuss the CMR operation and compare patient outcomes after both SR and CMR.

PATIENTS AND METHODS

Institutional review board approval was obtained (#1908679868 approved August, 29, 2019) for retrospective review of our 5-year case series conducted from February 2019 to February 2024 at a single academic institution in the United States. Informed consent was waived by the institutional review board. We previously published criteria for diagnosis of SRS[1] to clarify the diagnosis beyond a positive hooking maneuver that is typically used as the sole criterion. However, we have found our previous criteria to be too narrow. We now define SRS as spontaneously occurring and recurrent focal pain in 1 or more false rib intercostal dermatomes that can be reproduced on physical exam and correlates with palpable subluxation of the same false rib(s). Points of detachment and subluxation are often visible on computed tomography coronal images (Figure 1), which aids in confirmation of diagnosis. All patients diagnosed clinically using these criteria with SRS were given the options of conservative management with physical therapy versus surgical repair. The technique we offered initially was SR. As we encountered failed SR cases we developed the CMR technique and selectively offered either operation, depending on specific complexity of the cases. Distinct anatomical issues that led to consideration for CMR included multiple ipsilateral slipped ribs, false rib deformities (Figure 2, *A*) or sharply hooked rib tips (Figure 2, *B*), tightly crowded or excessively wide spacing (Figure 2, *C*) of slipped ribs, dissociated costal margin as often is encountered in patients with a skeletal hypermobility disorder, and iatrogenic deformities created from previous CCE or SR. Over time, CMR demonstrated superior results so it became our operation of choice for all patients. We have previously published our CMR operative technique in video format.[35] Figure 3 demonstrates the completed reconstruction.

Initially, we assessed pain medication use, subjective breathing function, pain, disability, depression, and anxiety caused by SRS and tracked outcomes at 1- and 6-month postoperative time points. As we transitioned to CMR we extended patient follow up every 6 months out to at least 18 months. Patients completed the Örebro Musculoskeletal Pain Survey Questionnaire[36] at each pre- and postoperative visit to evaluate the subjective effect of the procedure on outcome measures using a 0 to 10 self-assessment of 7 quality of life indicators, and a basic overall quality of life total was calculated as a percentage of a maximum 70 points. Patients that reported dyspnea were asked to quantify their percentage of breathing quality, compared with normal, preoperatively and at each follow-up time point. Wilcoxon signed-rank sum testing was used to compare

FIGURE 1. Coronal computed tomography image of a patient with bilateral slipped ninth and 10th ribs. *Arrows* indicate the slipped ninth rib tips.

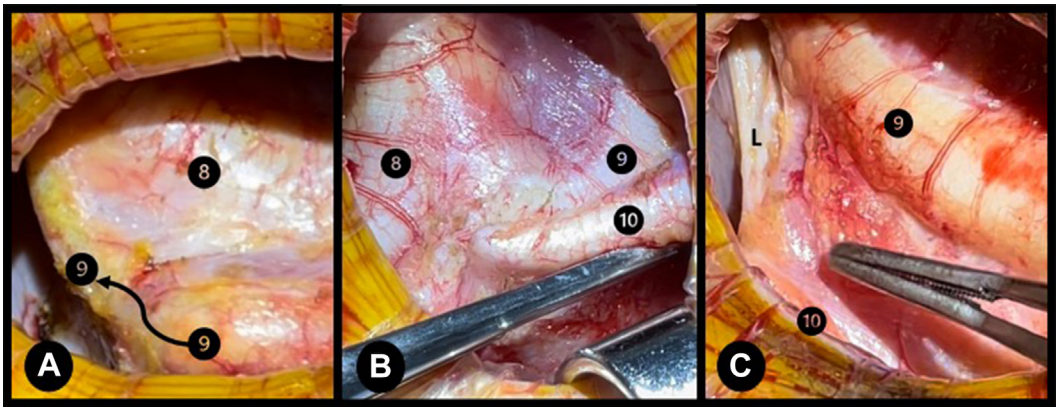


FIGURE 2. A, Left costal margin with deformed rib 9 and internal subluxation deep to rib 8. B, Sharply hooked 10th slipping rib. C, Widely slipped rib 10 attached only by an elongated ligament extending around the costal arch.

postoperative results with preoperative levels and determine statistically significant treatment effects. Use of neural modulating, narcotic, and nonsteroidal anti-inflammatory drug medications was also compared. We examined the operative site at each visit, when possible, to confirm the durability of the repair. In patients with staged bilateral repairs, results were analyzed after both sides were repaired.

RESULTS

Four hundred forty-nine patients with SRS were treated surgically. Demographic data are presented in Table 1. Mean age was 42 years and ranged from 14 to 84 years. Female patients accounted for 71%. Laterality of the affected side with SRS was equally distributed. The etiology of SRS was determined to the best extent possible based on history and physical examination (Figure 4). Trauma and the spectrum of connective tissue skeletal hypermobility disorders were the most common etiologies. Repetitive, asymmetric movements like twisting to 1 side, through their occupations or sports like golf and baseball, were commonly reported by patients to be the inciting factors for symptom onset. Iatrogenic cases were noted after upper abdominal operations with retractors or trocars placed at the costal margin or low thoracotomies with rib spreading. Patients with multiple pregnancies or obese patients that subsequently lost weight often noted symptom onset after a return to previous abdominal habitus. Most patients were on at least 1 prescribed medication to manage their symptoms at the time of our initial consultation. Almost half were on regular nonsteroidal anti-inflammatory drugs, muscle relaxants, benzodiazepenes, or nerve stabilizing drugs. Narcotic medications were used by 29%. One medication in total was taken by 32%, 2 by 27%, 3 by 11%, and 4 by 2%. Only 27% took no pain medication preoperatively, often stating that they were interested in a solution, rather than medical pain management.

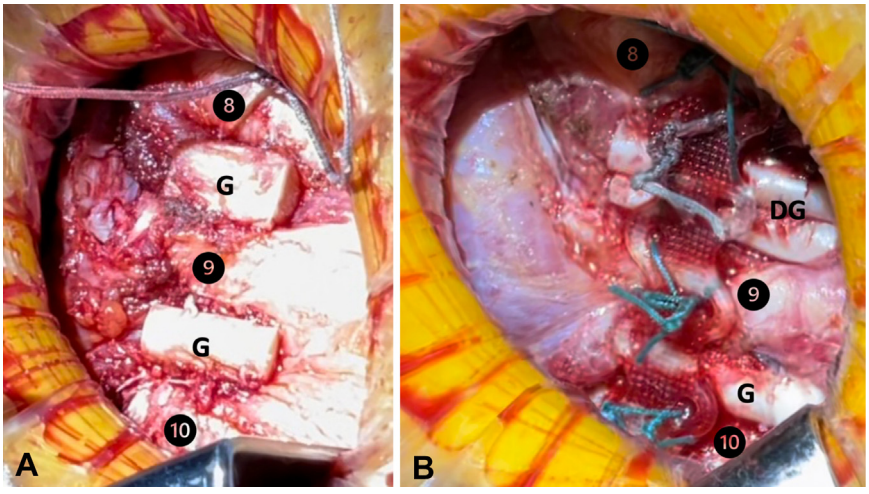


FIGURE 3. A, Reconstructed left costal margin after costal cartilage excisions of ribs 9 and 10 and autograft cartilage spacer placement. B, Fully reconstructed costal margin after bioabsorbable plating. Composite double graft (*DG*) placed in this case between ribs 8 and 9 to create greater intercostal spacing. *G*, Graft.

TABLE 1. Demographic data for all patients undergoing sutured repair or costal margin reconstruction

Demographic	N	%	Mean	Median	Range
Total patients	449				
Age			42	40	14-84
Sex					
Female	320	71			
Male	129	29			
Body mass index			27	26	17-45
Laterality					
Left	138	31			
Right	146	32			
Bilateral	166	37			
Suicidal ideations due to pain	99	22			

Patients commonly reported systemic symptoms. Dyspnea associated with SRS symptoms was reported preoperatively in 72% of patients. In those reporting a deficit, mean perceived breathing quality was 63%. About half of the patients also reported altered gut motility problems, although we did not formally assess this.

Mean overall preoperative quality of life was 37%, indicating SRS had caused a severe disruption in patients' lives. Previous or current suicidal ideations were present in 22% and uniformly attributed to unrelenting pain and frustration over lack of solution to their problem. A median of 6 physicians (mean, 8; range 1-75) had been consulted previously without definitive diagnosis or treatment in most. Eleven percent had undergone nontherapeutic cholecystectomy in an attempt to treat pain. Twenty-three percent had previously undergone some form of surgical treatment for their SRS, including CCE alone, CCE with vertical bioabsorbable plating, SR, and other various repair techniques.

Overall distribution of operative repairs is demonstrated in Table 2. SR (group 1) was conducted 303 times on 243 patients, accounting for 60 bilateral repairs. All but 3 patients were discharged the same day. After SR, iatrogenic pneumothorax occurred in 2 patients, postoperative hematoma requiring evacuation in 1, and deep wound infection in 1. No further immediate complications were observed. Recurrence or persistence of symptoms necessitated 69 revisions in 66 patients. Overall failure rate per number of patients was 27.2% and per sides repaired was 22.8%. We performed a second SR (5 bilateral) in the first 25 patients requiring revision and followed them for an additional 6 months. As CMR became available it was utilized for all revisions thereafter, and 39 revisions from sutured repair to CMR were performed. These patients crossed over to the CMR group and were followed according to our extended protocol. We realized through revising our own SR cases a technical pitfall in which we had initially undertreated some slipping ribs that did not fit our original definition of SRS. In addition to our revised cases, 2 patients underwent revision of their SR elsewhere.

In total, CMR (group 2) was conducted 312 times on 247 patients, accounting for 65 bilateral reconstructions. All but 3 patients were discharged the same day. Iatrogenic pneumothorax occurred in 1 patient and postoperative hematoma requiring evacuation in 1 patient. No further immediate complications were observed. Failure of the entire CMR occurred on 1 side in 1 patient who underwent bilateral CMR. Failure occurred due to early plate disruption and necessitated revision using the same CMR technique. Four patients regenerated a bony tip of 1 costal cartilage and required a minor operation to remove the bony rib tip that had caused recurrent nerve compression. In all 5 revision cases, we inspected the cartilage grafts and entire costal margin construct. All graft spacers were viable and well incorporated with firm, pliable scar tissue adhering them to the surrounding ribs. The cartilage excision sites had healed well with no evidence of herniation. We are aware of 2 CMR patients who underwent revision of their CMR elsewhere for reasons unclear to us. Overall need for revision of the entire CMR occurred in 1.2% of patients.

The immediate postoperative course was manageable in the outpatient setting. Outcome measures in the first 6 months were not statistically different between SR and CMR groups, but persistence or recurrence of symptoms in the SR group became apparent usually between 6 and 12 months (Figure 4). Median time to revision of initial SR was 14 months (mean, 16 months), which included several months of delay to actual revision in most patients due to logistical scheduling reasons. We discontinued routine follow up after 6 months in group 1 and collected no further outcome data beyond revision data in those who returned. With the advent of CMR we opted to follow patients in group 2 out to at least 18 months to extend the observation period beyond that in which we had observed failures in group 1. Thirty-six patients have currently been followed for at least 2 years. Mean preoperative pain scores in both groups dropped from 7.5 to 4.0 at 1 month ($P < .001$), and 2.5 at 6 months ($P < .001$). Mean quality of life scores (Figure 5) in both groups improved to 72% by 1 month ($P < .001$) and then to a mean of 82% by 6 months ($P < .001$).

Long-term data in group 2 CMR patients provided further insights. Outcome measures steadily improved over time. Mean pain scores dropped further to 2.0 at 1 year, 1.4 at 18 months, and 0.9 at 2 years ($P < .001$ all time intervals). Overall mean quality of life (Figure 5) increased to 87% at 1 year, 90% at 18 months, and 95% at 2 years ($P < .001$, all time intervals) and trended minimally higher in patients undergoing CMR as their initial treatment strategy, compared with reoperative patients. In the 72% of patients reporting a preoperative breathing deficit related to their SRS symptoms, self-reported breathing quality also steadily improved

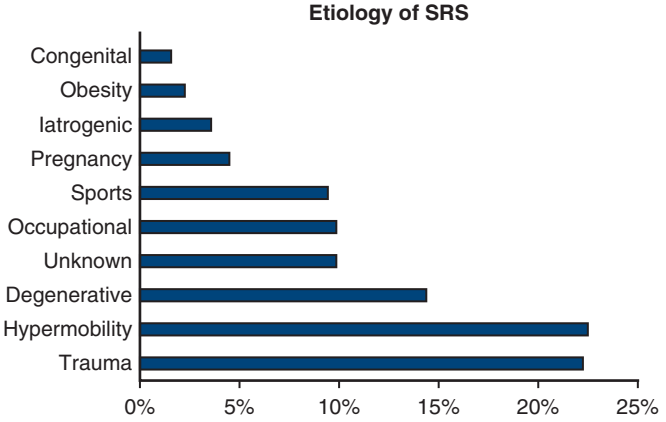


FIGURE 4. Etiology distribution in slipping rib syndrome (*SRS*).

over time from a baseline mean of 63% to a mean of 91% at 1 month, 96% at 6 months and 1 year, 97% at 18 months, and 98% at 2 years ($P < .001$ all time intervals).

Only 5% of the 45% of patients who had been prescribed neural modulating medications or nonsteroidal anti-inflammatory drugs preoperatively continued them at 18 months. Notably, 29% of patients had been taking prescribed narcotics preoperatively, but none required them for rib pain beyond 6 months.

Patients with significant prolonged pain issues during recovery were examined and/or imaged with computed tomography looking for breakdown of the reconstructed costal margin. Only 1 patient displayed these findings and required reoperation. Otherwise, the cartilage spacer grafts and proper intercostal spacing remained intact on all patients imaged, even beyond 2 years. The bioabsorbable plates were noted in many cases to have begun degrading and fracturing around 6 months, but this did not lead to disintegration of the reconstructed costal margins. We found that some patients have a prolonged recovery compared with others, but the usual time to resolution of severe symptoms was 2 to 3 months. We counseled patients with incomplete symptom relief to allow sufficient recovery of at least 6 months before considering reoperation, which proved successful in all but 2 patients that sought revision elsewhere and 4 that required minor excision of a regenerated costal cartilage tip.

TABLE 2. Distribution of operative repairs in entire slipping rib syndrome series

Operative details	SR	CMR
No. of patients	241	247
Postoperative complications	4 (1.7)	2 (0.8)
No. of initial procedures	303	312
Unilateral	243 (80)	247 (79)
Bilateral	60 (20)	65 (21)
Failures*	71 (23.4)	12 (3.8)
No revision offered	0	5 (1.6)
Revisions	69 (22.8)	5 (1.6)
Revisions at other centers	2 (0.7)	2 (0.6)
Revision technique utilized		
Revision to SR	30 (9.9)	0
Revision to CMR	39 (12.9)	1 (0.3)
Excision of regenerated rib tip	0	4 (1.3)
Unknown technique at other centers	2 (0.7)	2 (0.6)

Group 1 underwent sutured repair (*SR*). Group 2 underwent costal margin reconstruction (*CMR*). Complications included pneumothorax, wound hematoma, or infection. Values are presented as n or n (%). *Persistent or recurrent symptoms.

DISCUSSION

The present series represents the largest population of patients with SRS to date and thus provides a significant view into the disorder and appropriate solutions for it. Given the highly sensitive nature of the intercostal nerves and the constant, unrelenting compression caused by any movement of the torso, the disorder can become life-altering to those who experience it. Severe pain and postural instability can lead to depression, anxiety, withdrawal, insomnia, and limitation in activities of daily living. Frequent suicidal ideations were present in 22% of patients as a result of their pain and frustration. The multiple medical providers seen for the same symptoms and long duration of symptoms before obtaining a diagnosis emphasizes the difficulty patients often experience in establishing a diagnosis of SRS. A majority of the patients in our series researched their own symptoms, self-diagnosed, and self-referred after discovering patient-driven information on the internet and social media support groups.

Our series includes patients that had incomplete relief after CCE, often with ribcage and postural instability, intractable pain, diminished pulmonary function, and chronic gut motility issues. The authors' experience is that CCE without permanent stabilization can lead to complicated musculoskeletal instability issues and intractable pain syndromes that necessitate creative reconstructive solutions. These

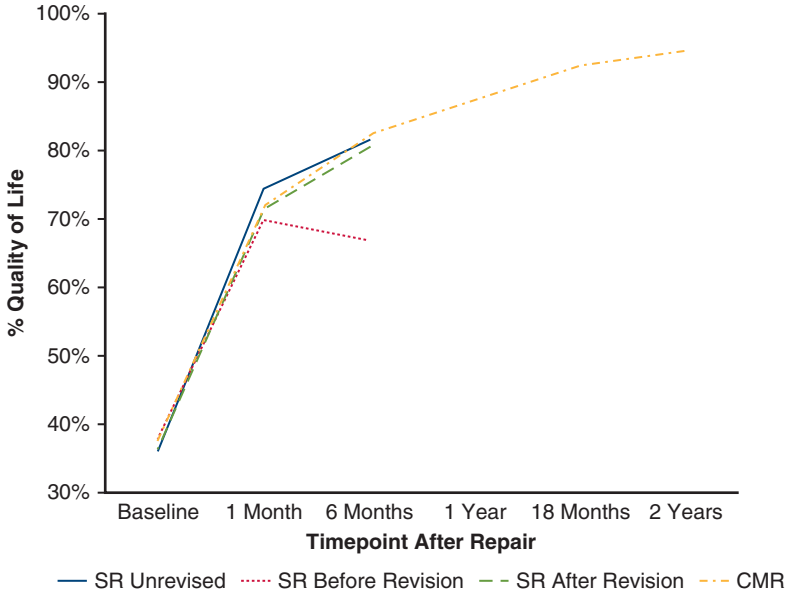


FIGURE 5. Overall quality of life following sutured repair (*SR*), costal margin reconstruction (*CMR*), and revision cases.

observations have been corroborated by other authors[2,8] and stabilization of the affected ribs with bioabsorbable vertical plating has been added by others to the standard CCE technique. Our technique similarly uses bioabsorbable plating, but only as a temporary splinting of the reconstructed costal margin, with permanent rib spacing and stability provided by the patient's own cartilage spacers and a permanent sutured weave of the spacers between the false ribs.

We have identified 4 basic tenets or goals for optimal reconstruction of SRS. First, the offending false rib cartilaginous tip compressing an intervening intercostal nerve against another rib must be identified and repositioned or excised. Standard CCE can accomplish this goal but can lead to rib migration or excessive hypermobility. Second, stability of the false ribs must be restored to prevent repetitive nerve compression between hypermobile ribs. This may be accomplished, in suitable straightforward cases, with simple suturing of the slipped ribs onto the costal margin.[1] Some patients with complex slipped rib anatomy who were originally treated with a suture-based repair had persistent symptoms. Third, proper intercostal space should be restored so the slipped ribs can lie in a neutral position without strain. In some cases of SR we have observed excessive strain after drawing the slipped ribs back to the costal margin. This underscores the importance of ensuring proper rib spacing and neutral positioning. A fourth tenet of optimal reconstruction is retention of costal margin flexibility without sacrificing stability. We have found our CMR technique to be suitable for use in almost any case with simple or complicated anatomical features.

We contend that the current standard of care in which analgesia, physical therapy, and nerve blocks are utilized, with the rare severe case of SRS being referred for surgery is outdated. These treatment modalities were reported by a large majority of the patients in this series to have been ineffective and often to have exacerbated their symptoms. When CCE without rib stabilization was the only available surgical solution, conservative measures may have been appropriate. Now that restoration of rib anatomy is a viable option, we believe it should be considered first-line treatment of SRS.

Our current recommendation is that SR may be considered as a surgical option in less complicated cases with single-level disease. However, long-term follow up in our study was limited in the SR group, limiting the conclusions that may be drawn about the outcomes after the technique in patients that did not require a revisional operation. Notwithstanding, we no longer use SR for any cases because our experience with failed cases leads us to believe that durability appears to be limited. If a provider does consider use of SR, any of the complicated anatomical features previously discussed should prompt consideration to employ the more complex CMR technique. Thorough understanding of the array of available surgical techniques is advised before providing SRS surgical treatment because success can be very nuanced.

We included pediatric patients as young as age 14 years in the current study with excellent results (Figure 6). We do not recommend CMR until an adolescent has matured sufficiently to near normal adult stature.

Some patients reported improvement in various visceral symptoms during the study. Dyspnea, altered gut motility, and tachycardia were common preoperatively. Many improved after repair and appropriate recovery time. We have not fully documented any of these effects through formal pre- and postoperative testing. The subject requires further investigation to establish any possible link of SRS to the presence or correction of visceral symptoms.

Two technical points about the CMR technique are noteworthy. First, intercostal nerves were carefully preserved during costal cartilage excision and all sutures placed to avoid nerve entrapment. It is possible that disruption of small nerve branches to the excised segments of cartilage could have provided relief. We have not attempted to quantify the sensory distribution after repair, but preservation of normal sensation was an overall goal with both repairs, as opposed to a partial or complete anesthetic effect that can be accomplished with procedures like nerve blocks or ablations. We did not encounter patients with anesthetic effect postoperatively. Second, only the anterior aspect of perichondrium is cauterized and removed with the costal cartilage excision step of CMR. Whether or not to preserve the posterior aspect of the perichondrium remains a surgical dilemma. The perichondrium is the posterior-most fascial layer. It is technically difficult to excise the perichondrium without entering the abdomen. Thus, excision could result in herniation of abdominal contents. Conversely, preservation of the perichondrium permits regrowth of the rib tips in some cases. We currently believe that perichondrial preservation is preferable because there is a low incidence of subsequent intercostal nerve compression, even when the rib tips regenerate, due to proper spacing of the false ribs apart from each other with cartilage spacers.

Inherent to this study are certain limitations. Outcome data were based on a subjective patient self-scoring system and may be altered by unknown patient biases. Moreover, the data compare a heterogeneous population of patients, 23% of whom had previously undergone 1 or multiple CCE procedures or various attempts at slipped rib repair. Inclusion of the more complex reoperative cases may have trended the total outcome conclusions toward less optimal results. A second limitation is that patients undergoing SR were only routinely followed for 6 months. Thus, assessment of long-term outcomes of SR and direct comparison to CMR patients is incomplete. The most useful conclusion that can be drawn from our SR group is that results are almost identical initially to CMR, but revision rates are comparable to published rates of revision in patients undergoing CCE. A third limitation in comparing the success of CMR to SR is our own evolution of SRS diagnosis and surgery. Not only did our ability to accurately diagnose SRS patients improve over time, but also our ability to address the full extent of rib instability improved over time. Thus, a portion of the reported greater success with the later CMR technique could be due to merely overcoming the learning curve over time. Lastly, many of the patients included in this study self-referred from another state or country, motivated to find a solution. The costs of travel

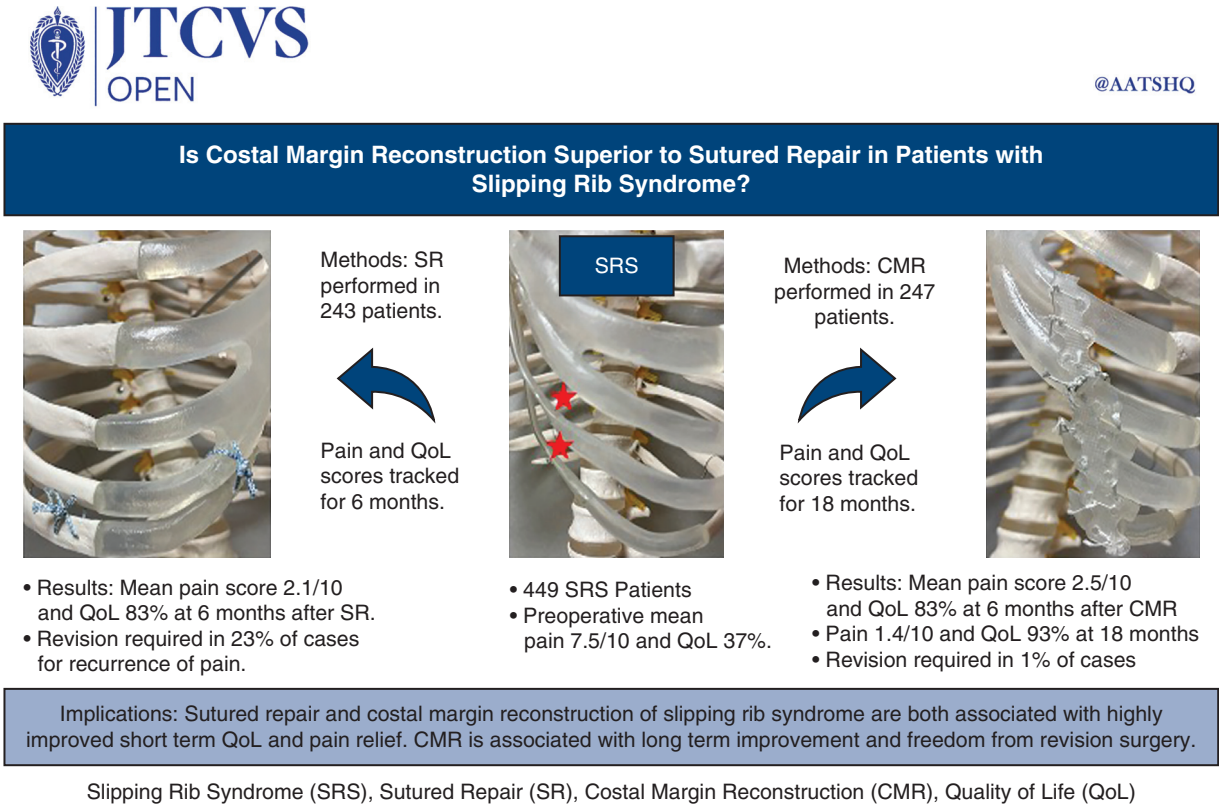


FIGURE 6. Graphical abstract. *SR*, Sutured repair; *SRS*, slipping rib syndrome; *CMR*, costal margin reconstruction; *QoL*, quality of life.

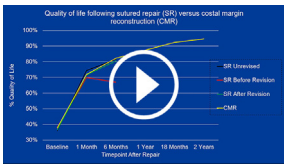
and out-of-network medical treatment may have prohibited other patients without sufficient resources from doing so. As such, socioeconomic bias may exist. Our goal is to disseminate the knowledge of SRS and successful treatment strategies broadly to expand access.

CONCLUSIONS

With CMR, protective and functional anatomy may be preserved and restored to optimal purpose. Results are durable with low risk of needing revision surgery. Minimally functioning, often drug-reliant patients with devastating problems can usually be returned to normal, drug-free, productive lives. We have found the care and results of these patients to be highly satisfying for both patient and provider.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/costal-margin-reconstruction-f-7236.



Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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