INTRODUCTION

Pectus carinatum (PC) is a chest wall deformity with a prevalence of 0.3–0.7% and is caused by abnormal growth of costal cartilage. It is 4 times more common in males than in females.1–4 Sternal protrusion, which progresses, especially during adolescence, often results in considerable body image concerns and psychological distress, or social impairment.5,6 Respiratory and cardiovascular symptoms are also frequently reported in PC patients. Most symptoms of pectus excavatum and PC can be considerably reduced after surgical repair.7–9

Sternocostal Instability after Ravitch Repair in Adolescents: 3 Case Reports and a Review of Surgical Techniques in the Literature

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Background: Ravitch repair is a common surgical procedure to correct chest wall deformities. In this procedure, a subperichondreal cartilage resection of the deformed parasternal cartilage, and if necessary a repositioning of the sternum, is performed. Insufficient regeneration of the resected cartilage may result in sternocostal instability or even floating sternum. This rare complication presents with symptoms of pain and exercise intolerance.

Methods: We describe sternocostal instability in 3 adolescent patients after the Ravitch procedure for pectus carinatum and reviewed the literature on this topic.

Results: Our patients suffered different degrees of instability. In all cases, we eventually achieved a satisfactory outcome. There is little literature on sternocostal instability. It is a rare complication, mainly occurring after reoperation by damaging the perichondrium.

Conclusions: Malunion of costal cartilage is a rare complication of open pectus repair. To achieve the best regeneration and stability of the sternum, less extended resection of cartilage should be performed and the number of cartilages resected should be limited. The perichondrium must be kept intact. Autologous grafts, growth-enhancing materials, and metal or bioabsorbable struts may contribute to stabilization and regeneration of the cartilage. (Plast Reconstr Surg Glob Open 2020;8:e2720; doi: 10.1097/GOX.0000000000002720; Published online 23 March 2020.)

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Nuss procedure in pectus excavatum. The more recently developed Abramson technique used for PC can be seen as the counterpart of the Nuss procedure. In this procedure, the sternal bone is compressed to its normal position by a pre-shaped subcutaneous tunneled bar with bilateral fixation to the ribs by means of stabilization plates.

The complications of open Ravitch repair include recurrence (8.4%), delayed wound healing (7.3%), persistent protrusion of cartilage (6.3%), thoracic dysthesia (4.2%), hypertrophic scar (3.1%), intraoperative pleural lesion (2.1%), and pneumothorax (2.1%).

Sternocostal instability may be described by a lack of sufficient bridging between sternum and ribs. In a floating sternum, the only attachment to the chest wall is its superior border (manubrium) and whatever lateral and inferior bands are present.

Due to its rarity, reports on the incidence and treatment techniques of sternal instability are limited. Malunion of the cartilage is a rare complication of pectus surgery and was first reported in 2001. It is caused by impairment of blood supply to the operated sternochondral region, which results in failure of cartilage regeneration, sometimes even years after the original procedure. The absence of cartilage between sternum and ribs can cause symptoms (pain, shortness of breath) and may lead to an unstable sternum. Operative reconstruction to regain chest wall stability might be needed.

We describe chest wall instability in 3 adolescent patients after Ravitch procedure for PC and reviewed the literature on postoperative sternocostal instability.

CASE REPORTS

A 15-year-old adolescent boy underwent open Ravitch repair for chondrogladiolar PC. The patient had symptoms of shortness of breath during exercise, aesthetic complaints, and social impairment and his chest wall was too rigid to be treated with an external compression device. We opted for the Ravitch technique over the Abramson technique (compression with a subcutaneous parasternal plate) because of the rigidity and asymmetry of the chest wall. The cartilage was bilaterally resected from the fourth rib downwards, but there were significant defects that caused instability.

Six months after the operation, the patient complained of a mobile seventh rib on the right side. The movement of this rib along the sternum caused pain and clicking. Reoperation showed that cartilage had failed to regenerate.

An extended resection of the cartilage was performed (including perichondrium). The cartilage did not regenerate and the patient was satisfied with the result.

A 17-year-old adolescent girl underwent open correction for chondromanubrial PC (pectus arcuatum). She had aesthetic complaints about her chest and symptoms of pain at the level of the deformity. Because of the chest wall rigidity in pectus arcuatum patients, a Ravitch repair technique was performed. Costal cartilages were removed bilaterally from the level of the second rib downward. A wedge was sawn out of the sternum at the level of the sternum deformation and the sternum was placed in a correct position.

The postoperative hospital stay was uneventful. One year later, the patient complained of pain on the left side of the sternum at costal cartilages 2–3. Ultrasonography showed 2 mm interruption of the 2 cartilages.

In a second operation, the scar tissue was removed. The cartilage was covered with the left pectoralis muscle. Symptoms disappeared initially; however, after 1 year the pain recurred. In a third operation, a debridement of the costal cartilages 2, 3, and 4 was performed and 3 Locked Compression Plates (1 straight and 2 volar T-plates) were placed to fixate the sternum to the ribs.

Four months later, the patient complained of pain at all costal cartilage sites on the left and shortness of breath. CT thorax showed no signs of bridging of costal cartilage.

Seven months after fixation, the plates were removed and peroperative bridging of the earlier defects was seen. The pain disappeared and the patient was able to resume daily activities.

A 16-year-old adolescent boy underwent an open Ravitch repair of his rigid pectus excavatum because of symptoms of shortness of breath and aesthetic complaints. Three years after surgery, he was reoperated because of an unstable thorax due to the failure of regeneration of costal cartilage and complaints of pain and instability during exercise.

At first, the mobile rib was fixated with sutures, but problems recurred. Therefore, the loose costal cartilage was shortened. Because his complaints persisted, the patient was referred to our institution. During physical examination, the patient could actively put his left rib cage over his sternum (see Video [online], which displays the patient (case 3) with extensive sternocostal instability at our outpatient clinic before operative stabilization).

During the fourth operation, we found malunion on multiple levels of costal cartilage (Fig. 1). The chest instability was mainly caused by the large defect on the left side from the fourth rib downward, but there were significant bilateral defects that caused instability.

The scar tissue was removed and the thorax was stabilized with 3 Stratos fixation bars. The proximal bar was placed behind the sternum, the middle, and distal one pre sternally. A prolene mesh was placed as sublay under the rectus abdominis muscle and fixated with prolene sutures to support the lower cartilage defects (Fig. 2).

At the follow-up, the thorax was stable and the patient could gradually resume activities.

One year later, a computed tomography scan of the thorax showed a broken proximal bar. Regeneration of costal cartilage or consolidation could not be evaluated.

Three months later, the bars were removed. During this operation, there was still residual instability over 3–4 levels on the left side. Fibrosis was removed and demineralized bone left behind. Two of the defects were bridged with rib matrix plates. One lower loose rib was left untouched. Five months later, the patient was satisfied. There was no pain and no instability of the chest. Patient resumed sports and work activities. A chest x-ray showed intact rib matrix plates.
DISCUSSION

In our pediatric hospital, we perform around 25 Ravitch procedures and 4 Abramson procedures per year for PC. In addition, every year approximately 120 patients start external compression treatment. For pectus excavatum, we perform around 45 Nuss procedures per year and approximately 35 patients start vacuum bell therapy each year.

In our history of pectus surgery, we experienced 5 cases of sternocostal instability after Ravitch procedure (Table 1). Three of these cases were described above.

Chest deformities can be improved with surgery; however, in children, surgical repair is associated with a higher recurrence rate and may affect costal cartilage growth and cause sternocostal instability or even a floating sternum.16,18

Only 2 studies describe the management of a floating sternum in a very small group of patients and included mainly adult patients.16,19

It is suggested that scar tissue within the perichondrium may interfere with cartilage growth and chest wall development, causing possible chondrodystrophy with reduced growth of the chest wall.16,20

Often, costal cartilage resection is extended onto the bony rib at the costochondral junction to obtain the optimal thoracic shape, however even minor damage to the perichondrial sheaths may cause incomplete cartilage regeneration, which can lead to instability. Extended resection of cartilage may interfere with the rib growth plates in children, which are located at the costochondral junction. Children undergoing a reoperation are especially at risk. The technique of minimal cartilage resection and temporary support with a strut has provided better
results than the more extended cartilage resections performed 15 years ago.9,15,21

Sternocostal instability can be treated with bone grafts to obtain stability in the absence of any regenerated cartilage. When cartilaginous remnants are available, they can be used to fixate the sternum. Renz and Reyes19 reported excellent results after reconstruction of costal cartilage with interposition of bone graft between rib and sternum and stabilization with metal Adkins struts when there was a complete absence of costal cartilage.16

Stability can also be achieved by stabilizing the sternum with metal struts, plates or bars. Adams22 already described this in 1951. Nowadays, even bioabsorbable struts are available.15,21

In a study of Calik et al,17 costal cartilage resection in young rabbits affected the chest wall development, especially in the anteroposterior direction, and thoracic growth was retarded when growth centers at the costochondral junctions were not preserved and the number of cartilages resected was not limited.23

Xu et al23 studied the effect of damage to the perichondrium and suturing the perichondrium into a tube-like structure or leaving it open. The non-damaged perichondrium that was stitched in a tube-like structure regenerates and remodeled best.23

A few studies describe new attempts to promote neochondrogenesis. In rabbits, applying platelet-rich plasma or human amniotic fluid into the perichondrial beds after resection showed an increased chondrogenesis.24,25

Based on our limited experience on sternocostal instability and what we have learned from these 3 cases, it is difficult to offer any treatment algorithm for these patients. The most important aspect to consider in reoperating these patients seems to be stabilization of the sternal bone and the chest wall. This can be achieved primarily by preserving the perichondrium and limiting the amount of resected cartilage (only the deformed cartilage and if asymmetric, only a minimal wedge at the nondeformed side) and secondarily by struts (retro- or parasternal or rib fixation plates), fixation wires, or even meshes. The authors would recommend to first perform a debridement of the old tissue at the level of the malunion.

**CONCLUSIONS**

There is little literature on malunion of cartilage after Ravitch repair. It is a rare complication mainly occurring after reoperation by damaging the blood supply and the perichondrium. It may cause symptoms of pain and instability that have great impact on patients’ lives.

To achieve the best regeneration of costal cartilage and stability of the sternum, a less extended resection of cartilage should be performed and the number of cartilages resected should be limited. The perichondrium must be respected and kept intact.

Our patients suffered different degrees of instability. In all cases, we eventually achieved a satisfactory outcome. In the last 2 patients, we achieved satisfactory stabilization; however, regeneration of cartilage might have been achieved earlier and 1 or 2 reoperations might have been prevented by immediate stabilization of the sternum.

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**Table 1. Our Experience with Sternocostal Instability or Floating Sternum**

| Patient | Sex | Age (y) | Surgery—Instability (m) | Type of Instability | Type of Operation (s) | Successful Stabilization and/ or No Symptoms | Reoperations |
|---------|-----|---------|-------------------------|---------------------|----------------------|---------------------------------------------|--------------|
| Case 1  | M   | 15      | 6                       | 1 level (local)     | Extended resection cartilage | Yes                          | 1            |
| Case 2  | F   | 17      | 12                      | 3 levels (local)    | Extended resection and later plate stabilization | Yes                          | 3            |
| Case 3  | M   | 16      | 36                      | 8 levels (Floating sternum) | Fixation by sutures, later shortening of cartilage, later plate stabilization (stratos/rib matrix) and bone graft/mesh | Yes                          | 4            |
| Case 4  | M   | 15      | 7                       | 1 level (local)     | Extended resection cartilage | Yes                          | 1            |
| Case 5  | M   | 17      | 14                      | 1 level (local)     | Extended resection cartilage | Yes                          | 1            |

F, female; M, male.
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