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Risk Factors and Techniques for Safe Pectus Bar Removal in Adults After Modified Nuss Repair

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ABSTRACT

BACKGROUND The Nuss repair involves implants designed for removal after 2 to 3 years. Although rare, significant complications can occur with bar removal, and the incidence of these complications may be higher in adults. This study was performed to review complications and risk factors associated with bar removal and discuss strategies to improve operative safety.

METHODS A retrospective study was performed including all patients after pectus excavatum repair who underwent Nuss implant removal at Mayo Clinic Arizona (Phoenix, AZ) from 2013 to 2022.

RESULTS In total, 1555 bars were removed (683 patients; 71% men; median age, 34 years[(range, 15-71 years]). Of the removals, 12.45% of patients had bars placed at outside institutions. Major complications were rare, with bleeding most common (2.05%), followed by pneumothorax (0.88%), infection (0.59%), and effusions (0.44%). Most major bleeding (85.71%) occurred from the bar track during removal and was controlled by packing the track. One patient required subsequent hematoma evacuation and transfusion. Bleeding secondary to lung injury was also successfully controlled with packing. Bar removal in 1 patient with significantly displaced bars required sternotomy and cardiopulmonary bypass as a result of aortic injury. Risk factors identified for bleeding included sternal erosion ($P < .001$), bar migration ($P < .001$), higher number of bars ($P = .037$), and revision of a previous pectus repair ($P = 0.001$). Bar migration was additionally associated with major complications ($P < .001$). Older age, although a risk factor for overall complications ($P = 0.001$), was not a risk factor for bleeding.

CONCLUSIONS Bar removal can be safely performed in most patients; however, significant complications, including bleeding, may occur. Identifying potential risk factors and being prepared for rescue maneuvers are critical to prevent catastrophic outcomes.

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The Nuss procedure has been performed to repair more than 50,000 pectus excavatum cases in the past 20 years,[1,2] with life-threatening incidents occurring in less than 0.1%.[3-9] The substernal bars are recommended for removal after 2 to 3 years.[10-12] Various techniques for bar removal have been described.[13,14] Although often performed on an outpatient basis, bar removal can rarely be associated with significant and even life-threatening complications that require invasive measures such as sternotomy or thoracotomy.[2,7,8,15,16] Case reports of major complications, including lethal outcomes, have been documented.[7,8] Several risk factors have been reported that increase the likelihood of complications with bar removal.[3,8,9] At least 1 report noted a small increased risk of complications in young adult patients.[17]

Because more adults are undergoing pectus repair with the Nuss procedure, an understanding of a potentially increased risk is necessary. This study reviews our experience with bar removal in a population of predominantly adult patients and evaluates the risk factors

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that were predictive of complications. Intraoperative strategies and rescue maneuvers for control of bleeding are additionally discussed.

PATIENTS AND METHODS

Institutional Review Board approval was obtained for a retrospective cohort study of patients who underwent pectus bar removal at a single institution (Mayo Clinic Arizona, Phoenix, AZ) from February 1, 2013, to April 1, 2022. Electronic medical records were reviewed, and data were collected, including patient demographics, procedure, hospitalization, and postoperative follow-up.

Complications were classified according to the Clavien-Dindo classification.[18] Bar migration was graded internally as follows: grade II, migration with significant rotation or posterolateral shift with an impact on repair or clinical outcome but not requiring surgical intervention, only monitored clinically; and grade III, migration with significant rotation or a posterolateral shift requiring operative management for removal or revision. Osseous overgrowth was determined by the surgeon's assessment during the operation.[19]

Statistical analysis was performed using SPSS software version 28.0 (IBM Corp). Variables were summarized as mean ±SD or median (range) for continuous variables and as count (percentage) for categoric variables. Comparisons between groups were performed using the Wilcoxon rank-sum test, the Student *t* test, or the χ^2 test as appropriate. To determine an association between independent variables (risk factors for complications) and the dependent variable (presence of complications), binary logistic regression was performed. A *P* value <.05 was considered significant.

Our technique for Nuss repair has been previously published,[16] and it was modified after October 2015 with the addition of 2 reinforcement sutures.[20] A "hammock" suture, which is a FiberWire (Arthrex, Inc, Naples, FL) suture, is placed to reinforce the intercostal space containing the bar. The figure-of-8 FiberWire incorporates the rib above and below the interspace and is placed immediately lateral to the bar exit site to prevent it from stripping through the intercostal muscle. It allows the weight of the bar to rest on the FiberWire suture "hammock" vs the intercostal muscles. Additionally, sternal fixation is added as medial fixation (Figure 1).

The bar removal procedure in our study patients is briefly described as follows:

The patient's blood type was identified and screened. Arterial line monitoring was performed throughout the procedure. The patient was positioned supine with longitudinal gel rolls placed parallel to the spine and arms tucked at the sides. The groin area was prepared and draped into the field in case femoral access became necessary. WalterLorenz Surgical Assist Arms (Zimmer Biomet) were placed at the head of the bed. Intravenous antibiotic was administered before incisions were made.

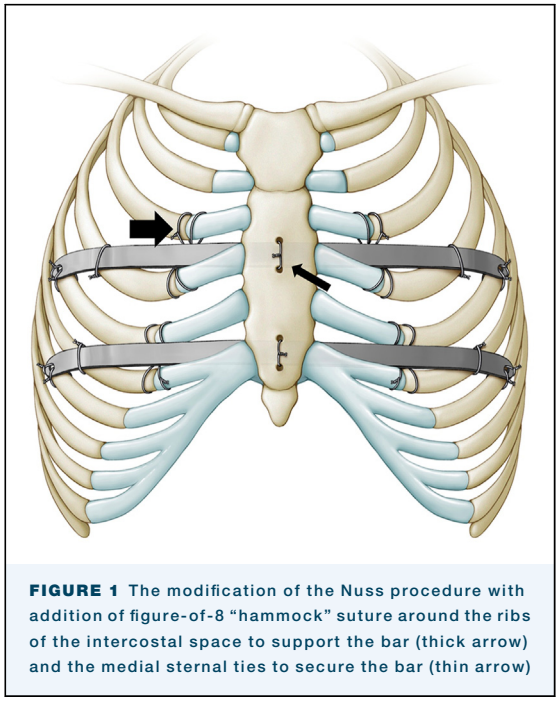

FIGURE 1 The modification of the Nuss procedure with addition of figure-of-8 "hammock" suture around the ribs of the intercostal space to support the bar (thick arrow) and the medial sternal ties to secure the bar (thin arrow)

The patient's previous incisions were opened, and the muscle was elevated laterally until the bars were identified. If stabilizers were used, securing mechanisms and stabilizers were removed first. All accessible FiberWire sutures were identified, cut, and removed. Deeper, medial sutures were left in place unless they obstructed bar removal. Sternal ties were not removed unless the ties were palpable and the patient requested their removal.

Fibrotic tissue and scar were divided and excised up to the entrance of the bar into the intercostal space. When ossification was present, an osteotome and a rongeur were used to remove the osteophytes. A Lewin bone clamp (CareFusion, Inc) (Figure 2A) was used to grasp the distal end of the bar through the islet, thereby allowing placement of the pectus removal bender (Zimmer Biomet) to straighten the bars bilaterally. The bars were removed by preference from the patient's right side; therefore, it was critical that the left bar end was unbent to almost flat (Figure 2B). A slight couple of degrees of downward curve remained because a bar that was overbent up toward the anterior chest wall could theoretically scrape the internal mammary artery as it was pulled through the chest. Bars were never rotated (unless migration and rotation had occurred, and removal required derotation) or "wiggled" during removal. All bars were removed with transesophageal echocardiographic

visualization, and a final echocardiogram was performed at the time of closing to confirm the absence of pericardial effusion or changes.

Once bars were removed, excess bone prominences were debrided down flush to the chest wall, and hemostasis was obtained. Liposomal bupivacaine and 0.25% bupivacaine were injected intercostal and subcutaneously. Use of hemostatic agents was common, including Floseal (Baxter Inc) or Surgicel Powder (Ethicon Inc). The muscle, subcutaneous tissues, and skin were closed with a running absorbable suture. Postoperative patient's chests were wrapped in a Velcro (Velcro Co)-elastic abdominal binder recommended for wear for a minimum of 24 hours. Postoperative imaging was performed in the recovery unit. Patients were released home when deemed stable and appropriate for safe discharge, with follow- up scheduled within 24 to 72 hours.

If bleeding occurred from the bar track on removal, epinephrine-soaked pledgets (Figure 3) (Codman Surgical Patties, Codman & Shurtleff, Inc) and sponges were packed into the bar track and were held under pressure for a minimum of 10 to 20 minutes. The packing was removed, and if bleeding recurred, Floseal with Surgicel Sheeting (Ethicon Inc) and repacking with epinephrine-soaked pledgets were used for an additional time until hemostasis was obtained. The echocardiogram and the patient's vital signs were monitored throughout the procedure. Critical intrathoracic bleeding was an indication for prompt conversion to video-assisted thoracoscopy or sternotomy. Femoral lines were used for blood transfusion or cardiopulmonary bypass in the case of cardiac injury.

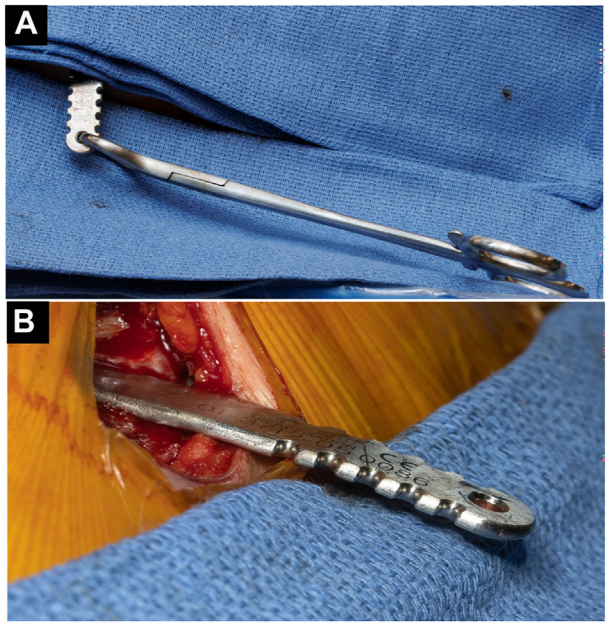

FIGURE 2 (A) Lewin bone clamp is attached to the islet to pull the bar from the right side. (B) Left side of the bar is straightened to nearly flat with only a few degrees of curve remaining.

FIGURE 3 Epinephrine-soaked pledgets are used in packing in case of bleeding from the bar track.

RESULTS

In total, 1555 bars were removed from 683 patients. Bars placed at an outside institution constituted 12.45% of our patient cohort, with the bars removed for procedure revision or complications related to the bars (Table 1). Less than 3% of cases had a single bar removed; most (85.00%) were from another institution undergoing revision repairs. The remaining 15.00% were early removals for pain or migration.

Table 2 reviews minor and major complications. Major bleeding occurred in 2.05%, with the majority from bar tracks. Most (85.71%) major bleeding cases were controlled with packing and are detailed in the Supplemental Table. There was a significant decrease in the rate of overall complications seen in the bar removal procedures of our patients correlating with the time periods before and after October 2015 (13.9% vs 4.0%; $P < .001$).

Significant risk factors for overall complications, major complications, and major bleeding included sternal

TABLE 1 Patient Demographics and Bar Removal Information

Characteristics	Values
Total number of patients	683
Male, n (%)	486 (71.16)
Age, y, median (range)	34 (15-71)
Preoperative Haller Index, median (range)	4.09 (2.04-26.7)
Pectus repair of bar removal, n (%)	
Primary	
Nuss or modified Nuss	515 (75.40)
Hybrid modified Nuss with plating[21]	73 (10.69)
Revision	
Modified Nuss after Failed Nuss	41 (6.00)
Modified or hybrid Nuss after failed Ravitch	39 (5.71)
Hybrid Nuss for Thoracic Dystrophy	15 (2.20)
Duration bars in place, y median (range)	3.18 (0.17-10.05)
Bars removed, n (%)	
1	20 (2.93)
2	455 (66.62)
3	207 (30.31)
4	1 (0.14)
Total duration of surgery, min, median (range)	
Bar removal only (n = 617)	51 (16-177)
Bar removal and other procedures (n = 66)	136 (35-374)
Percentage outpatient procedures, n (%)	
Bar removal only (n = 617)	575 (93.19)
Bar removal and other procedures (n = 66)	37 (56.06)

TABLE 2 Minor and Major Complications in 683 Patients Who Underwent Pectus Bar Removal

Complications	Frequency	%
Minor complications		
Bleeding from bone and ossification	9	1.32
Hematoma	9	1.32
Pneumothorax requiring imaging follow- up	26	3.81
Infection		
Wound	14	2.05
Suspected: antibiotics administered empirically	9	1.32
Culture confirmation: antibiotic therapy	5	0.73
Urinary tract	2	0.29
Chest pain persistent beyond 30 days	14	2.05
Seroma	3	0.44
Nausea and vomiting	3	0.44
Urinary retention requiring Foley catheter	3	0.44
Major complications		
Bleeding	14	2.05
Bar track	12	1.76
Packing of track	11	1.61
Thoracoscopy with hematoma evacuation or transfusion	1	0.15
Lung injury		
Packing lung	1	0.15
Aortic injury		
Sternotomy or bypass with repair	1	0.15
Pneumothorax requiring chest tube placement	6	0.88
Infection requiring incision and drainage	4	0.59
Pleural effusion requiring thoracentesis	3	0.44

erosion, bar migration, and revision of a previous pectus repair. In addition, overall complications were associated with older age, and major bleeding was associated with a higher number of bars removed (Table 3).

Osseous overgrowth of the distal ends of bars was seen in 73.80% of our patients (n = 504) and was associated with a longer duration of bars remaining in place (odds ratio, 2.18; 95% CI, 1.71-2.79; $P < .001$).

COMMENT

The Nuss procedure has quickly become the standard of care for repair of pectus excavatum in young patients.[10] Extension of the repair procedure to adults has been controversial, although it is becoming more common.[16,22] Bar removal is usually a safe outpatient procedure.[23,24] Most reports include pediatric and adolescent cohorts with limited information about the potential for increased complications in older adult populations.[17,25] This study identified complications and risk factors associated with Nuss bar removal in our predominantly adult patient cohort.

Major bleeding was a significant complication, occurring in 2.05% of removals. Most patients had identifiable risks, but not all. One-half had implants in place >4 years, although this was not found to be a significant risk factor. Sternal erosion ($P < .001$), bar migration ($P < .001$), revision of a previous failed pectus repair ($P = .001$), and removal of 3 or more bars vs 2 or fewer bars ($P = .037$) were all significant risk factors identified. Other institutions have reported major bleeding as a complication but with less frequency. Bilgi and colleagues[17] reported on 246 patients Nuss bar removals, with 1.2% experiencing major bleeding. In their cohort, patients undergoing removal of 2 bars vs 1 were more likely to have complications ($P = .03$) and secondary interventions, including thoracoscopy and chest tube placement.[17] Although the mean age of their patients was only 17.7 years, patients who had complications were on average older (20.5 years) than patients who did not (17.2 years). These investigators and others hypothesized that older, larger, and anatomically more complex patients required multiple bars that led to increased sternal pressure to achieve repair.[16,17,22] This subsequently resulted in increased difficulty during bar removal. In our cohort, older age was a significant risk factor for overall complications ($P = .001$), but not bleeding ($P = .945$). With a median age of 34 years and major bleeding occurring in patients aged 22 to 53 years, along with 98% of cases having ≥2 bars, the risk may have been inherent in the baseline characteristics of our cohort. Two published series of bar removals in adult patients have a significantly younger median age for comparing risks and complications. The cohort reported by Nyboe and

TABLE 3 Risk Factors Correlating With Complications With Nuss Bar Removal (Overall and Major Complications)

Risk Factors	Odds Ratio	95% CI	*P* Value
Overall complications			
Sternal erosion	3.112	1.315-7.365	**.010**
Bar migration	2.167	1.216-3.864	**.009**
Redo surgery	2.045	1.215-3.441	**.007**
Age	1.029	1.011-1.047	**.001**
3 bars	1.219	0.834-1.781	.307
Body mass index	1.034	0.978-1.093	.238
Years of bars in place	1.040	0.876-1.234	.658
Major complications			
Sternal erosion	16.55	6.03-45.45	**<.001**
Bar migration	6.46	2.71-15.43	**<.001**
Redo surgery	7.24	3.12-16.77	**<.001**
Age	0.99	0.96-1.03	.796
3 bars	1.98	0.87-4.51	.101
Body mass index	0.97	0.86-1.09	.650
Years of bars in place	0.98	0.67-1.42	.921
Major bleeding			
Sternal erosion	20.09	6.12-66.00	**<.001**
Bar migration	7.75	2.60-23.10	**<.001**
Redo surgery	6.03	2.04-17.86	**.001**
3 bars	3.13	1.07-9.13	**.037**
Age	0.99	0.95-1.05	.945
Years of bars in place	1.29	0.91-1.85	.147

Boldface indicates statistical significance.

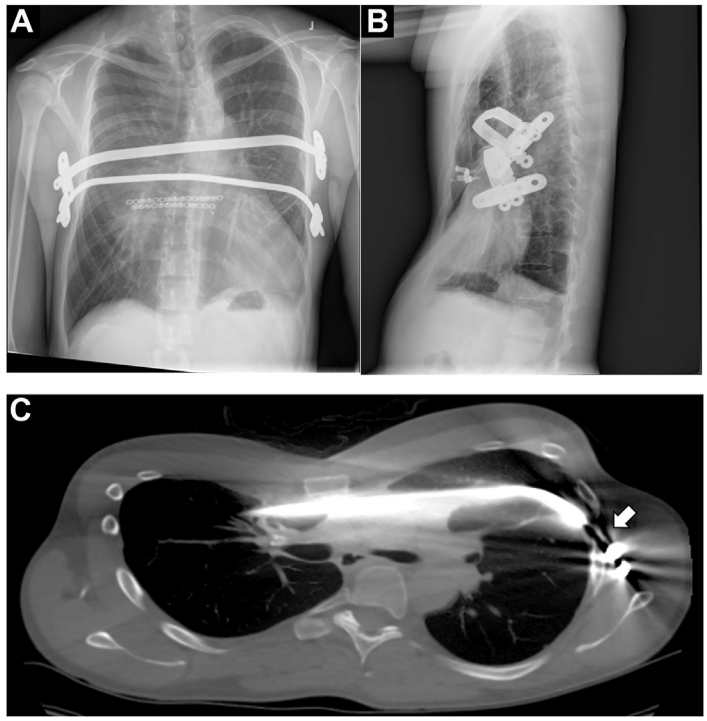

FIGURE 5 (A) Anteroposterior chest roentgenogram showing slight misalignment of Nuss bars. (B) Lateral chest roentgenogram with clear evidence of severe bar migration. (C) Computed tomography showing intrathoracic bar migration compressing mediastinal structures with lateral exit (arrow).

colleagues[26] (334 patients; median age, 19 years) experienced 3 hemothoraces (1 requiring open surgical treatment and 2 chest tubes). Most patients (84%) had single bars. Hsieh and colleagues[25] had a higher number of double bars (71% of patients; mean age, 22.8 years) but reported no major bleeding. These investigators did not find age to be a risk factor in their cohort.

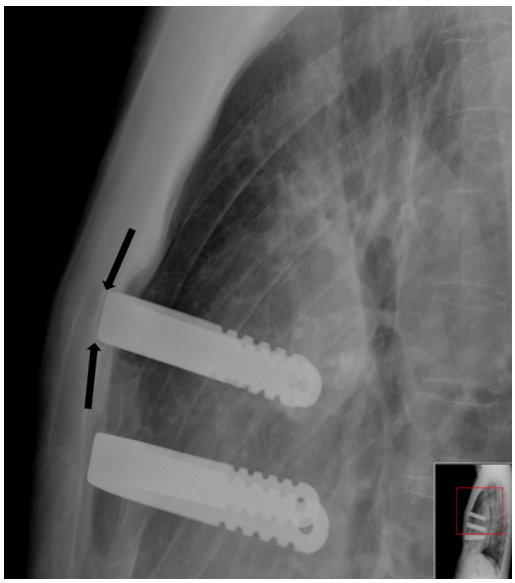

FIGURE 4 Erosion into the posterior table of the sternum by the pectus bar can be seen on a lateral chest roentgenogram (arrows).

Safe removal must be prefaced by safe placement and securing of bars. Removal of bars that were significantly malpositioned incurred significant risks of major bleeding ($P < .001$) and major complications ($P < .001$). When removing migrated bars, especially when the bars were placed by outside institutions, a strategic rescue strategy with groin lines and standby cardiopulmonary bypass was critical in preventing mortality.[27,28] Our experience with an aortic injury during removal of bars placed at another institution required femoral-femoral bypass and sternotomy to control bleeding.[27] Catastrophic outcomes described in the literature are almost always secondary to injury during placement or subsequent significant bar migration that allowed prolonged contact with mediastinal structures.[7,8,29]

Reviewing our Nuss experience, our bar removal complication rate dropped significantly over time. Specifically, evaluating time periods before and after mid-2015, we observed that overall complications with bar removal decreased from 13.9% to 4.0% ($P < .001$). This change likely included more than just experience

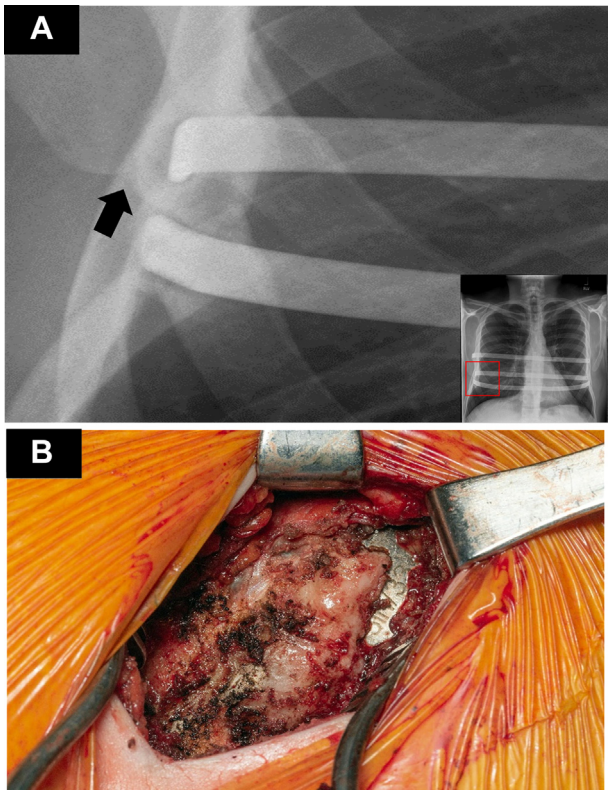

FIGURE 6 (A) Magnification of chest imaging showing ossification around distal end of bar tip (arrow points to osseous overgrowth). (B) Intraoperative photograph of patient with ossification exposed during bar removal procedure.

because it coincided with technique modifications (Figure 1). Both "Hammock" figure-of-8 intercostal space reinforcement and sternal fixation modifications were added to our Nuss procedure in late 2015. These modifications have decreased our observed incidence of grade II or III bar migrations (3.66% vs 0.44%), sternal erosion (2.80% vs 0.30%), and major bleeding (2.05% vs 0.66%) during bar removal.

Other reported risk factors include a history of bleeding, pericarditis, and previous infection or allergy.[9] Previous procedures, including Ravitch, thoracotomy, open heart surgery, and lung injury, have also been discussed as a source of complications.[29,30,31] Six of our patients who experienced major bleeding underwent revision procedures, and 3 of them had undergone previous Ravitch or open-type procedures (Supplemental Table). All but 1 of these patients had bars that we placed at the time of the revision procedure and were subsequently removing. It is our hypothesis that extensive adhesions, bleeding, air leak, and inflammatory processes occurring with a reoperation may increase the risk of complications with bar removal, although other risk factors, including bar migration and sternal erosion, were present in some of these cases (Table 3). What was clear, however, is that having a revision procedure was a risk factor for overall complications and bleeding.

Proper planning for bar removal requires imaging.[9] Both posteroanterior and lateral chest roentgenograms are necessary to view sternal erosion (Figure 4) and assess positioning of bars (Figures 5A, 5B). If significant bar migration is noted, we recommend computed tomography for 3-dimensional views of bar proximity to mediastinal structures (Figure 5C). Imaging can also assess ossification and plan fluoroscopy if needed for bar location assistance (Figure 6).

Major complications are rare with bar removal; however, when they do occur, they can be life-threatening.[2,7,8,29] All our bar removal procedures are performed in the main hospital operating rooms because the outpatient facility does not have capacity to accommodate critical-level procedures. Other institutions may provide different opportunities. Surgeons should be prepared with a preplanned rescue strategy (Supplemental Figure)[9,12]:

- Set up for a worst-case scenario: positioning; monitoring; intravenous access; blood products available.
- Have immediate access to rescue equipment: sternal saw; open instruments; thoracoscopy set up; materials for packing.
- Rehearse a strategy before the case with the operating room team should a critical complication occur.

We routinely perform transesophageal echocardiography during these procedures, whereas other institutions recommend use of intraoperative echocardiography should concern for bleeding occur.[9] The echocardiographic visualization allows confirmation of a successful pectus repair without residual compression, and removal of bars does not affect this. Additionally, transesophageal echocardiography can confirm that there are no concerning findings (ie, new pericardial effusion) with bar removal.

Our technique for removal includes unbending of the bars and not moving the bars back and forth (wiggling) to pull them through. We agree with Park and colleagues[13] and Noguchi and colleagues[23] that straightening the bar tips for removal may be advantageous and leave a few degrees of curve. We recommend removal of all stabilizers and securing methods first. If possible, all bars should be freed from scar tissue and ossification, unbent, and ready for removal before any bars are removed. Should significant bleeding occur with bar removal and emergency chest entry be required, all implants will need to be removed quickly because they impede access. If 1 bar is noted by radiography to be

concerning for migration or sternal erosion, we recommend removal of this bar last.

RESCUE STRATEGIES. Almost all bleeding occurred from the bar track within seconds of implant removal. This bleeding was likely secondary to erosion into the internal mammary artery or an intercostal artery. The bleeding appeared brisk and substantial because the contained fibrotic track acts as a funnel. In all but 1 case, this bleeding was controlled by packing the track.[17] Most of the time, there is no bleeding into the intrathoracic space unless the track was broken.[3,9] We adopted the use of Codman surgical pledgets soaked in epinephrine 0.1% (Figure 3) from our otolaryngology colleagues. These pledgets are used for control of nosebleeds and are easily pushed deep into the bar track, followed by a sponge. Toselli and colleagues have[24] a strategy for bleeding in the bar track that uses a safety string. An umbilical tape is tied to the end of the bar during removal, and then a sponge can be attached to umbilical tape and pulled back through the bar track if the track bleeds.[24]

If bleeding is intrathoracic and the patient's condition is stable, thoracoscopy into the intrathoracic space may avoid an invasive procedure[3]; however, adhesions in the chest may inhibit visualization and access to control bleeding. If possible, confirm that bleeding is intrathoracic and identify the source of hypotension before opening a patient's chest.[3] Femoral lines for blood transfusion or bypass can be considered if significant cardiac injury is suspected. If a patient has life-threatening instability and evidence of intrathoracic injury and bleeding, there should be no hesitation to perform open sternotomy. The surgeon should be ready to perform this procedure if necessary.

STUDY LIMITATIONS. This was a retrospective study and therefore subject to all the inherent biases and limitations of this study design. This was a single-surgeon, single-institution study, and our center is a high-volume institution with a dedicated pectus program. Therefore, it may be difficult to extrapolate these findings to other facilities.

CONCLUSION. Bar removal can be safely performed in most patients; however, complications may occur, including significant bleeding. Sternal erosion, bar migration, revision surgery, and age were all significant risk factors for overall complications in our older patient cohort. Not all patients with major bleeding had identifiable risk factors, and surgeon experience and preparedness for critical rescue maneuvers are necessary to prevent morbidity and mortality.

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DISCLOSURES

Dawn E. Jaroszewski declares serving as a consultant with IP/royalty rights under Mayo Clinic Ventures with Zimmer Biomet, Inc. All other authors declare that they have no conflicts of interest.

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