Minimally Invasive Repair of Pectus Carinatum

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Background. **The second most common deformity of the anterior chest wall, pectus carinatum, is a diverse deformity that has been largely managed using open techniques. This study reviews clinical experience with a newly designed bar for minimally invasive repair of pectus carinatum.**

Methods. **We reviewed the records of all patients recorded in our Chest Wall Deformities Clinical Database. Between January 2006 and November 2016, minimally invasive repair of pectus carinatum was performed in 172 patients. All met the criteria of a "compression test" of 10 to 25 kg/cm^2. The mean age was 17.3 years, and 22.7% had a positive family history of a congenital chest wall deformity. Symmetric and asymmetric deformities were treated. During our study period, we designed 4 different bar configurations and their related stabilizers. All patients are assessed every 3 to 6 months. After 2 to 3 years of follow-up, the bar and the stabilizers are removed.**

Results. **Of 172 patients, 97.1% tolerated the procedure very well. The operation was a mean length 76.6 minutes. Average blood loss was 40 mL. Mean hospital length of stay was 3.7 days. Complications included pneumothorax, wire breakdown/rib cut, wound infection, severe pain, skin hyperpigmentation, nickel allergy, and overcorrection leading to excavatum. Patients returned to routine activity in 10 to 14 days. With a mean follow-up of 29.8 months in bar removal patients, 130 of 172 (93.8%) reported excellent results.**

Conclusions. **Minimally invasive repair of pectus carinatum with the technically modified fourth-generation bar and its securing system has advantages of low morbidity, short hospital stay, and excellent cosmetic results, even in asymmetric cases.**

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Pectus carinatum (keel chest, pigeon breast), which is characterized by anterior protrusion of the sternum or of the adjacent ribs, or both, is the second most common congenital anterior chest wall deformity [1]. The disease is named after the keel (carina) of ancient Roman ships. It accounts for 5% to 22% of all anterior chest wall deformities and is seen less frequently than pectus excavatum, occurring in about 0.06% of all live births [2, 3]. Males are affected two to four times more frequently than females [3].

The hypothesis for the etiology involves defective metabolism or overgrowth of the sternocostal cartilages [4, 5]. A genetic origin of this deformity was suspected according to the family history; at least 25% of the patients indicate another family member involvement of a chest wall deformity [6, 7]. Although the presentation in carinatum is symmetric protrusion of the anterior chest wall, several variants have been identified [5, 8]:

1. Classic pectus carinatum or the chondrogladiolar variant: 90-degree forward angle between the xiphoid process and the lower part of the sternum causes the protrusion of the gladiolus (body) of the sternum. In this type, the maximum prominence is at the sternoxiphoid junction. Lateral depressions of the ribs may accompany and are sometimes severe enough to cause a reduction in internal thoracic volume (Fig 1).
2. Costomanubrial variant or pouter pigeon breast (pectus arcuatum): protrusion of manubriosternal junction and the adjacent ribs. The xiphoid process is contiguous to the end of the sternum in the sternal axis without angulation. This variant is sometimes referred to as combined (carinatum and excavatum) deformity (Fig 2).
3. Lateral pectus carinatum: unilateral prominence of elongated costal cartilages with concomitant tilting of the sternum toward the opposite side in various angles. This is the asymmetrical type (Fig 3).
4. Horseshoe chest: costal cartilages are protruding [5, 9] (Fig 4).

The physiological effects of the deformity can be severe and may also affect physical, social, and mental health. Patients often experience feelings of shame and embarrassment with low self-confidence, and they camouflage their chests with clothing or posture [5, 10–12]. The deformity becomes evident in early adolescence and becomes progressively more severe until skeletal maturation ends. As the deformity becomes more severe, most patients experience progressive exertional dyspnea [7].

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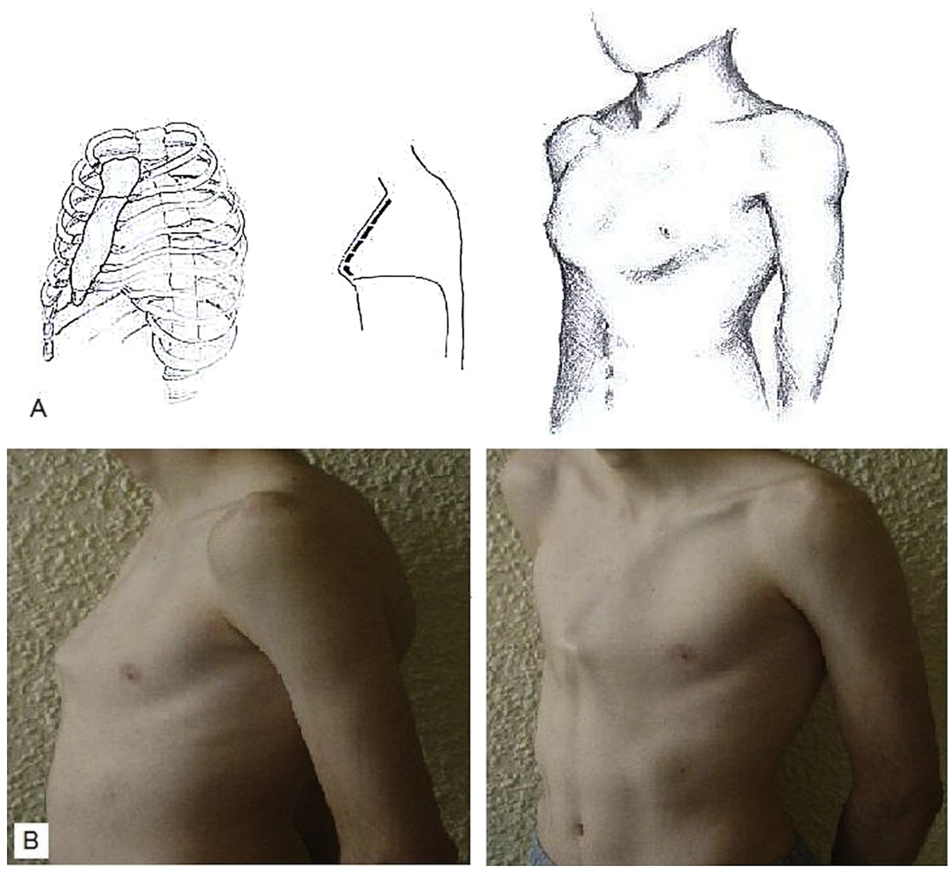


Fig 1. (A) Anatomical illustrations and (B) patient photographs of classic pectus carinatum.

The radiologic severity of the disease is described by the Haller Index of pectus severity [8]. The presence of kyphosis increases the severity of the index. Carinatum patients in their adolescence seek treatment advice.

With the advent of less extensive surgical techniques, first described by Abramson [13], the disadvantages of surgical repair, such as pain after an open repair, long hospitalization, and limited correction, have started to fade [14, 15]. Even combined treatment management using compressive orthotic braces, with or without surgical repair, has broadened the age limitation for treatment [16]. Since our first experience of 18 patients [17], our efforts on better stabilizing the bar on the ribs to have a better compression of the sternum have led us to manufacture the fourth-generation bar and stabilizer system (Patent No. TR 201310715Y, Tasarımmed, Istanbul, Turkey). In this study, we present the largest series of patients in the literature who have undergone minimally invasive repair of pectus carinatum (MIRPC).

Material and Methods

This study involves the retrospective evaluation of our prospectively collected data from the Chest Wall Deformities Clinical Database. This database includes all patients who have presented to the Marmara University Hospital for treatment of chest wall deformities between August 2005 and November 2016. The data of 456 pectus carinatum patients are gathered from the database. Institutional Review Board approved the review of data, and written informed consent was obtained from the patients or their parents depending on the patient's age. Patient satisfaction was evaluated using questionnaires preoperatively and at 6 months postoperatively. Photographs of all patients were taken before and after surgical correction for comparison.

Patients

Between January 2006 and November 2016, 172 patients (154 male, 18 female) with pectus carinatum underwent MIRPC, 250 of 456 patients underwent compressive orthotic brace treatment, and 34 underwent open surgical correction. After clinical evaluation and physical examination were completed, posteroanterior and lateral chest roentgenograms and pulmonary function tests were obtained. Computed tomography of the chest was obtained only in patients who had complex or asymmetric carinatums. All deformities that underwent MIRPC (n = 172) were the chondrogladiolar (classic pectus carinatum) or lateral (asymmetrical pectus carinatum). Patients with the chondromanubrial type (pectus arcuatum) were offered open repair with plate insertion, and patients with a

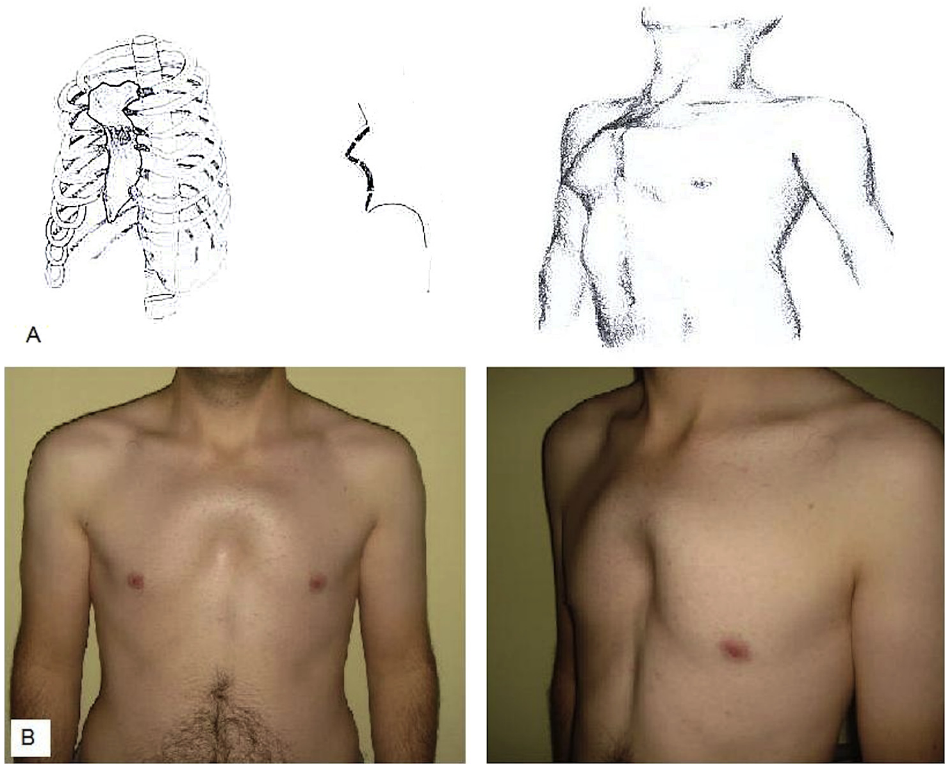


Fig 2. (A) Anatomical illustrations and (B) patient photographs of arcuatum deformity, costomanubrial variant.

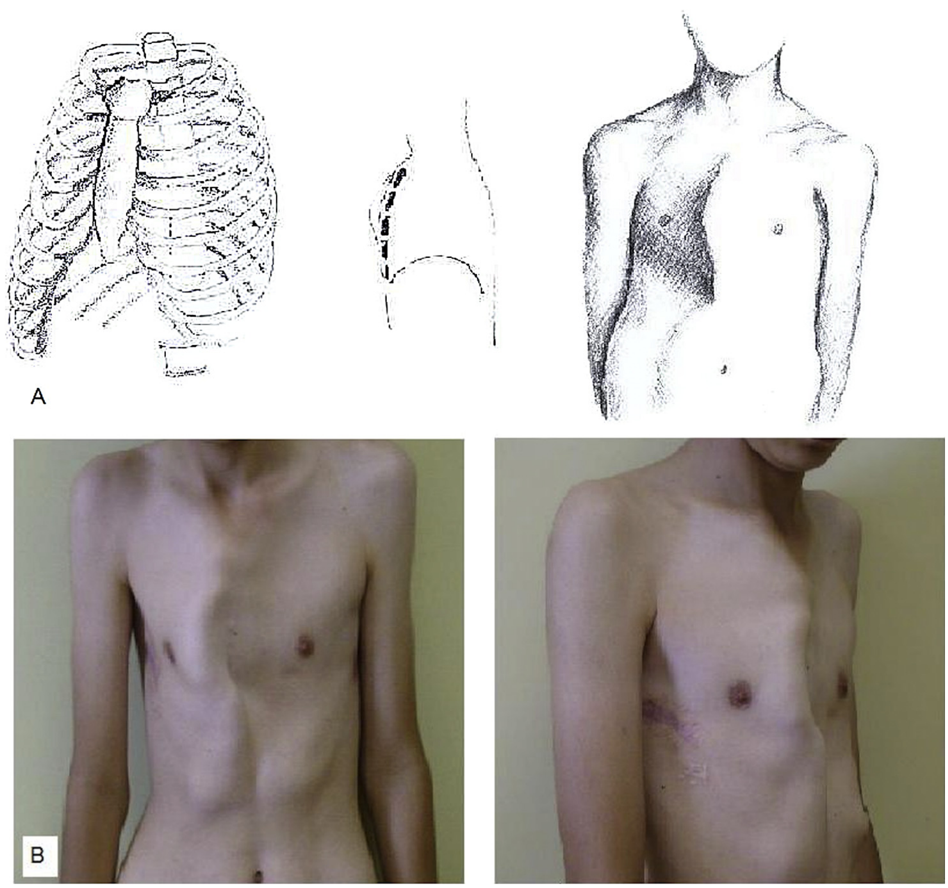


Fig 3. (A) Anatomical illustrations and (B) patient photographs of lateral pectus carinatum, asymmetrical type.

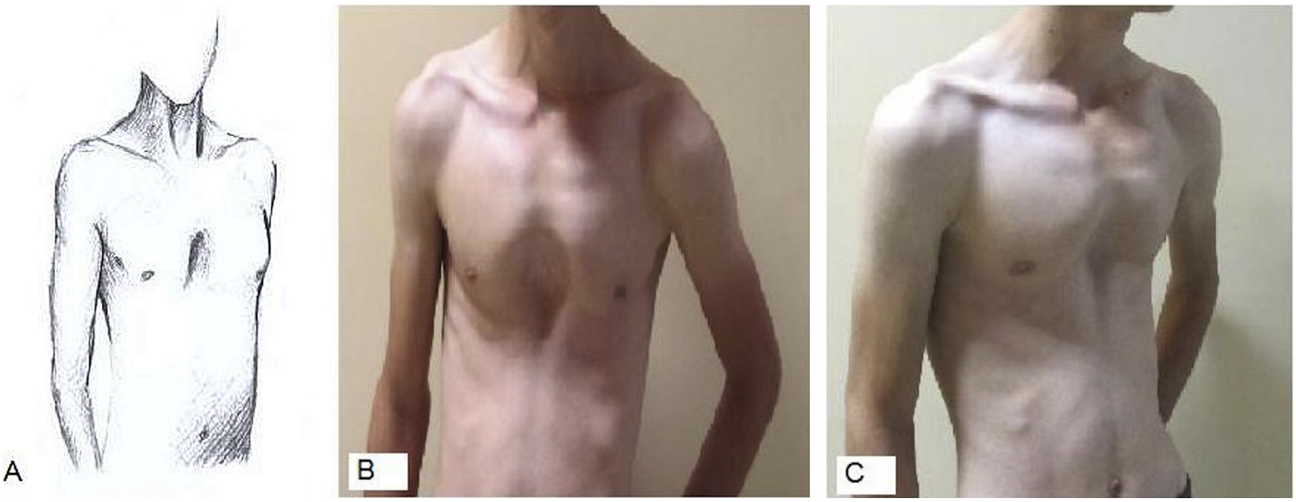


Fig 4. (A) Anatomical illustrations and (B and C) patient photographs of horseshoe type.

horseshoe chest underwent open repair with plate insertion and excavatum bar placement (n = 32).

Every pectus carinatum patient underwent a preoperative “compression test” to determine the flexibility of the sternum. A digital pressure calculator is used to measure the pressure in kg/cm^2 while the examiner presses over the sternum using the device with the patient leaning against a wall (Fig 5). Patients with pressures between 10 and 25 kg/cm^2 underwent MIRPC and those with pressures above 25 kg/cm^2 underwent open surgical repair (n = 2).

The patients who underwent MIRPC were a mean age of 17.3 years (range, 10 to 35 years). A family history of congenital chest wall deformity was documented in 39 patients (22.7%), 78 (45.3%) had asymmetric deformity, 4 (2.3%) had concomitant kyphosis or kyphoscoliosis, or both, and 1 (0.6%) had Marfan syndrome. Ten patients (5.8%) had undergone inguinal hernia repair surgery previously.

Surgical Technique

The patient is placed supine with both arms abducted. General anesthesia with single-lumen intubation is applied. The surgical method includes insertion of a specially designed bar, which is a mixture of nickel and steel, through midaxillary incisions by creating a submuscular tunnel anterior to the sternum. The first step of the operation is to configure a bar of an appropriate length for remodeling of the chest. This is done by modeling the chest using an appropriate length template while the surgeon’s fist is used to apply pressure over the protruded sternum to form a normally appearing sternum. Then the bar is bent into a convex configuration as the template model.

The second step is to define the level of the chest where the bar is going to be placed, which is chosen according to the level of maximal protrusion of the sternum. Two midaxillary incisions parallel to the maximal protrusion are performed, and the serratus anterior muscle fibers are separated. Two neighboring ribs on both sides for the placement of the stabilizers are chosen. An incision is made in the periosteum of the selected ribs, and a periosteum elevator is used to make a tunnel between the periosteum and the rib. The ribs are encircled through this tunnel, subperiostally with a specially designed hook and subsequently with a suction catheter. The suction catheter serves as a sheath for sternal cables (Pioneer Sternal Cable System, Marquette, MI) to avoid pneumothorax. Ventilation is withheld during this maneuver to avoid any harm to the lungs.

The suction catheter is removed after the sternal cables are placed, and the patient is connected back to the ventilator. The stabilizers are secured subperiosteally to the 2 concurrent ribs using the sternal cables. At this stage, attention should be paid for the stabilizers to be perpendicular to the horizontal line that connects both midaxillary incisions. A specially designed introducer is used to create a subcutaneous tunnel anterior to the sternum and posterior to the pectoral muscles while manual pressure is applied over the sternum. A polyvinyl chloride chest tube is passed through the tunnel attached to the introducer. The configured bar is inserted through

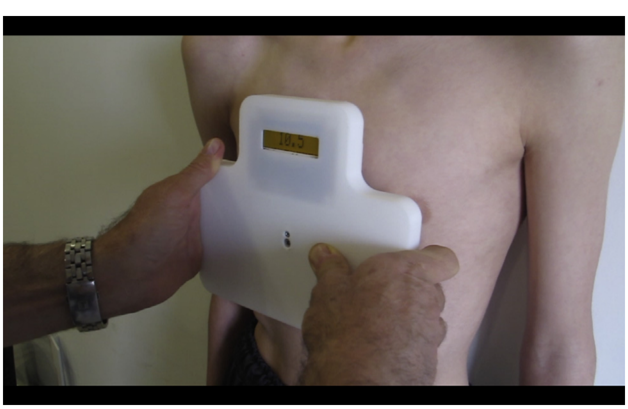


Fig 5. Compression test using the digital pressure calculator.

the tunnel, using the chest tube as a guide, with the concavity facing posteriorly. Our fourth-generation bar has 6 holes at each end. This bar slides into the stabilizer and is secured to the stabilizers with clips on both sides at an appropriate level while manual pressure is applied over the sternum until the desired shape is achieved.

The wounds are closed in layers with absorbable sutures. Postoperative posteroanterior and lateral chest roentgenograms are obtained to check the bar placement and to look for pneumothorax (Fig 6). We do not use epidural anesthesia because intravenous patient-controlled anesthesia and oral analgesics are adequate for pain control. Prophylactic cephalosporin antibiotics are administered perioperatively for 72 hours.

Early mobilization of the patient is encouraged. Patients returned back to school or work in 2 to 3 weeks. All patients are assessed every 3 to 6 months. The bar and the stabilizers are removed after 2 to 3 years of follow-up.

During our study period, we designed 4 different bar configurations and their related stabilizers. The first-generation bar with sharp grooves used big screws to secure the stabilizer to the bar. The grooves were too sharp, and aligning the screws to the grooves was difficult (Fig 7A). The second-generation bar with broad grooves had small pins to secure the stabilizer. The grooves were broader; however, aligning the bar and the stabilizers was still difficult because each pin should face a groove while manual pressure is applied over the sternum (Fig 7B). To overcome this problem, the third-generation bar was invented, which had grooves on one side of the tip that a single pin could be inserted into (Fig 7C).

With the invention of the fourth–generation bar, the system has completely changed. The fourth-generation bar is manufactured with 6 holes along the tips. As this bar slides into the stabilizers while manual pressure is applied over the sternum, a clip is placed to the appropriate hole to hold the bar in place (Fig 7D). This clip is a little pin that holds the bar in the stabilizer by preventing the bar from sliding off the stabilizer (white star in Fig 7D).

Another evolution was performed at the material used to secure the stabilizers to the ribs. The stabilizers were first secured to the ribs using single-layer sternal wires (n = 20). We then used double-stranded sternal wires (n = 59). Now we use sternal cables (Pioneer Sternal Cable System) to secure the stabilizers (n = 93).

Results

Mean length of the MIRPC operation was 76.6 minutes (range, 45 to 120 minutes). Average blood loss was 40 mL. Mean hospital length of stay was 3.7 days (range, 2 to 10 days). Patients returned to routine activity in 10 to 14 days.

Of 172 patients, all except 5 (2.9%) tolerated the procedure very well. We had to remove the first-generation bar in 1 patient at postoperative month 5 because of intractable pain and removed the fourth-generation bar in 4 patients at 8, 10, 23, and 40 days postoperatively, respectively, due to cosmetic dissatisfaction in 2 patients and intractable pain in 2 patients. One patient who was dissatisfied with his new chest underwent repeat MIRPC after the bar removal at 6 months.

Wire breakdown was observed with single- or double-stranded sternal wires in 9 patients (5.2%), and 3 (1.7%) were replaced with new wires. In the remaining 6 patients, because the wire breakdown occurred close to removal and did not cause any dislodgement, the broken wires were kept as they were and were removed during the bar removal. Two wire breakdowns with rib cut (1.2%) were observed with sternal cables.

Skin hyperpigmentation occurred in 3 patients (1.7%), and wound infections with the first three generation bars occurred in 17 patients (9.9%). Nickel allergy was observed in 5 patients (2.9%), and 2 of these patients underwent removal earlier than planned (at 12 months).

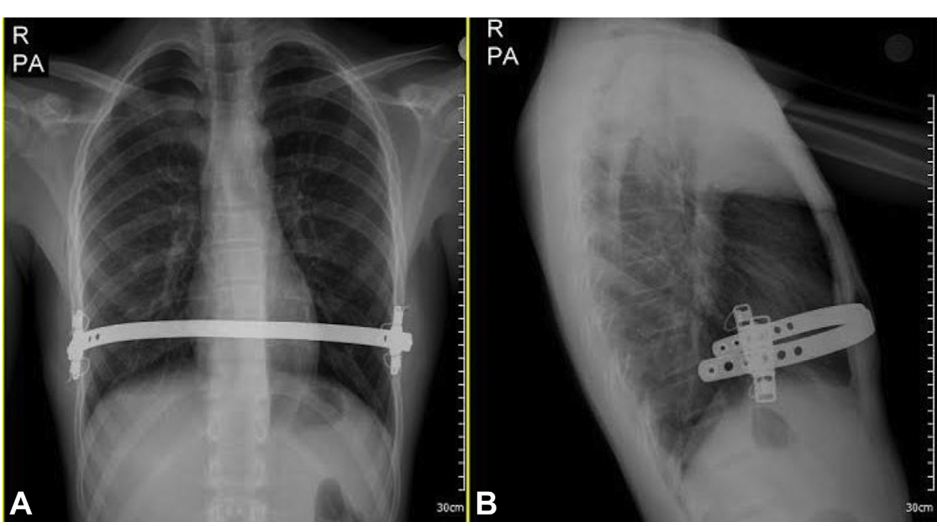


Fig 6. Early postoperative (A) posteroanterior and (B) lateral chest roentgenograms are obtained to check the bar placement and to look for pneumothorax. (PA = posteroanterior; R = right side.)

GENERAL THORACIC

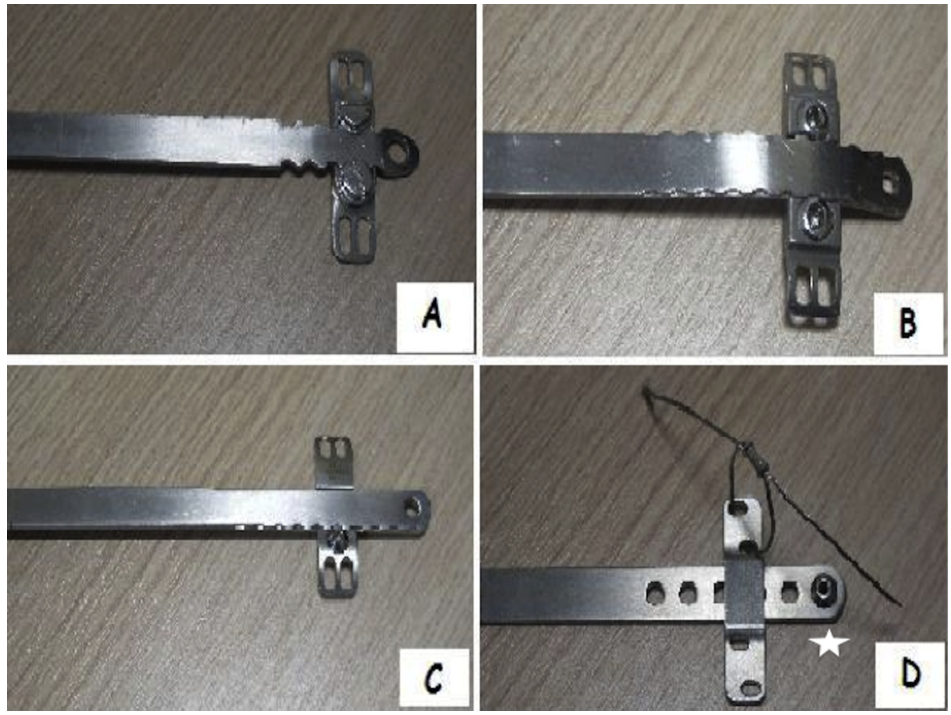


Fig 7. Photographs show the (A) first-generation, (B) second-generation, (C) third-generation and (D) fourth-generation bars. The white star in (D) indicates the clip which is a little pin that holds the bar in the stabilizer by preventing the bar from sliding off the stabilizer.

Only 1 skin infection occurred with the fourth-generation bar. Skin infections were treated with appropriate antibiotic regimens. None of the patients needed bar removal.

Pneumothorax was diagnosed in 12 patients (7%) postoperatively. Only 5 patients (2.9%) needed drainage with tube thoracostomy or needle aspiration. One patient underwent video-assisted thoracoscopic apical abrasion during his repair for wire breakage.

Bar tightening was required in 3 patients (1.7%) after inadequate correction of the carinatum deformity was detected during the follow-up. More manual pressure was applied over the sternum, and the clips were placed to the hole just adjacent to the one before.

Excavatum deformity of varying degrees developed in 10 patients (5.8%) during follow-up because of overcorrection (Fig 8). All of the patients with overcorrection underwent bar removal earlier than planned at 12 to 13 months after the MIRPC. The overcorrection had regressed spontaneously during the follow-up after the bar removal without any intervention in 9 of the patients. One of the overcorrected patients needed a placement of an excavatum bar. Carinatum deformity recurred in 4 of these patients, and they underwent compressive orthotic brace treatment.

Overall, 130 of 172 patients (75.6%) have undergone bar removal, with unsatisfactory results in only 8 patients (6.2%). The carinatum deformity recurred in 5 of 130 patients (3.8%). Four of the recurrence patients were the patients who were developing excavatum deformity and underwent early bar removal at 12 to 13 months. The bar in the fifth patient with recurrence was removed at 20 months, and he underwent repeat MIRPC. Average follow-up in patients who underwent bar removal was 29.8 months (range, 1 to 110 months).

Comment

The classic repair for pectus carinatum is the Ravitch procedure or its modified versions [18, 19]. The operative steps of these invasive procedures include elevation of pectoralis major muscles, subperichondrial resection of defective costal cartilages, and transverse sternal osteotomies. Although high success rates have been reported [7, 20], these major steps make up the disadvantages of long operating times, significant postoperative pain, long hospital stays, high blood loss, and scarring of the anterior chest wall [21, 22]. Within the last 10 years, minimally invasive correction of pectus carinatum has started to become popular [14, 15, 17, 21, 23, 24]. After the first successful MIRPC in our institution in January 2006, we have gained a considerable amount of experience and modified our technique and the bar. Repair of the deformity with the minimally invasive technique has overcome the disadvantages of the classic technique, resulting in satisfying esthetic outcomes with few complications.

The most appropriate period for the minimally invasive repair is when the deformity of the anterior chest wall becomes more prominent, which is during the rapid growth phase of puberty. The age range of the cohort in this study was 10 to 35 years (mean, 17.3 years) which is a little older, although the mean age is still in the puberty phase.

When the patient presents to our outpatient clinic, we perform a compression test to check the flexibility of the

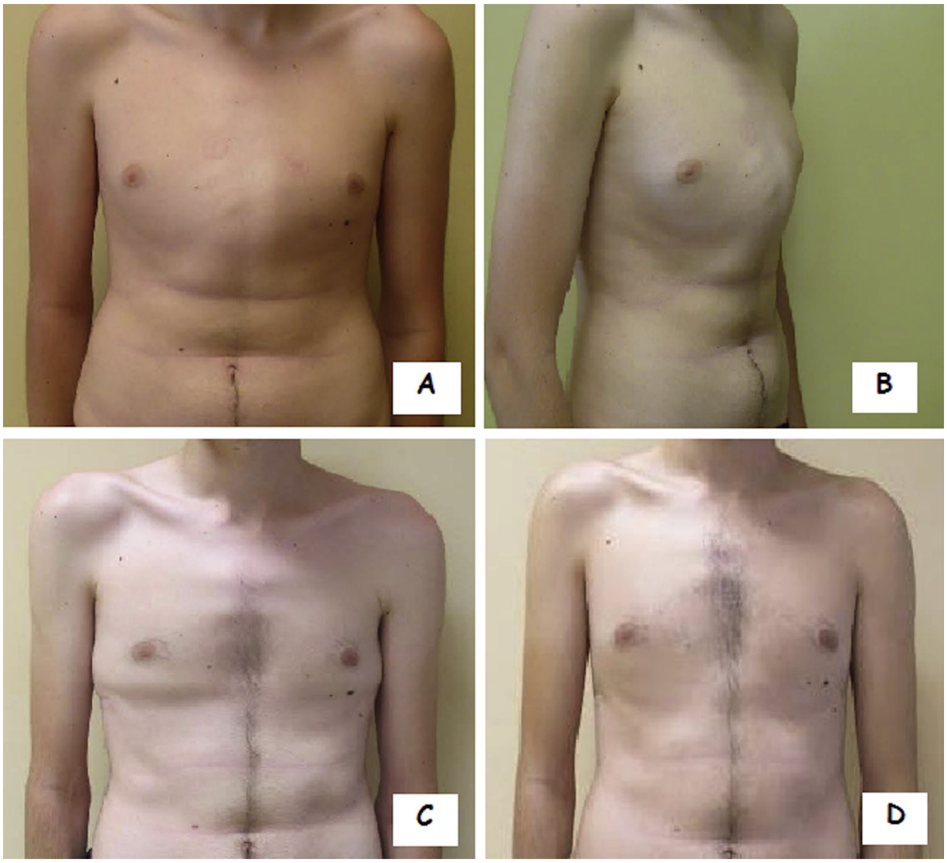


Fig 8. A 16-year-old patient with overcorrection leading to pectus excavatum. (A and B) Preoperative photograph of the anterior chest wall. (C) Overcorrection leading to pectus excavatum is seen at the 12-month follow-up, and the decision was made to remove the bar. (D) Photograph at 6 months after bar removal shows the pectus excavatum has resolved spontaneously. There was no recurrence of carinatum.

chest wall. The compression test is done by pressing over the sternum by a digital pressure calculator while the patient is leaning against a wall. If the compression force per cm^2 is less than 10 kg, orthotic bracing is recommended. In our group, 250 of 456 patients underwent compressive orthotic brace treatment. Brace treatment has some difficulties, including adherence to the therapy, difficulty in positioning of the brace during the night time, and difficulty in choosing the right brace type. A recent study of 114 patients who underwent dynamic bracing reported a failure rate of 15%. The main reasons for failure and longer bracing duration were asymmetry, older age, and smaller first drop in pressure of treatment [25]. If the compression force applied is between 10 and 25 kg, this means that the chest wall is flexible enough to repair it with MIRPC. If the force exceeds 25 kg, this shows that the sternum is too rigid to be compressed and the open surgical technique is performed. Rigidity of the chest wall rather than the age has a greater effect on making the treatment decision.

Chondrogladiolar (symmetric; Fig 9) and lateral carinatum (asymmetric) deformities both benefit from MIRPC. Our series included 78 asymmetric patients (45.3%; Fig 10). As the compressive pressure on the sternum and the protruded chondrosternal junctions is transferred to a fixed point (the vertebrae) and the cables are strong enough to hold the bar in place, asymmetric cases are corrected.

Early complications of MIRPC included pneumothorax (n = 12), of which only 5 patients needed drainage, wire breakdown (n = 3), wound infection (n = 9) and severe pain (n = 3). Late complications were wound infection (n = 8), skin hyperpigmentation (n = 3), wire breakdown (n = 6), nickel allergy (n = 5), rib cut by cables (n = 2), and overcorrection leading to excavatum (n = 10). Single-strand and double-stranded wire breakdowns observed as an early or a late complication led us to change the securing system to a more durable sternal cable system. Only 2 sternal cable breakdowns with rib cut were observed. We have overcome the rib-cut problem by extending the distance between the holes on the stabilizer.

Patients with wound infections were treated with antibiotics, and none needed bar removal. The bars in 2 of the 5 patients with nickel were removed earlier than planned. Excavatum deformity of varying degrees, caused by overcorrection, developed in 10 patients (5.8%). Excavatum deformity regressed spontaneously in 9 patients after the bar was removed. One patient underwent excavatum bar placement. Four patients with overcorrection received orthotic brace treatment as a result of carinatum recurrence.

We aim to keep the bar in place for at least 24 months. Earlier bar removal may cause recurrence of the carinatum. Bar removal in patients older than 18 years can be postponed to 36 or 48 months, depending on the

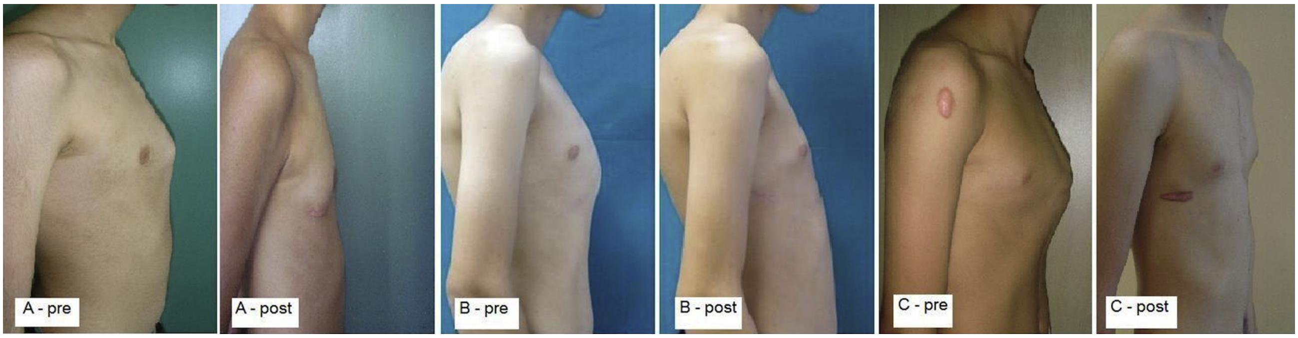


Fig 9. Preoperative (pre) and postoperative (post) photographs show patients with (A) mild, (B) moderate, and (C) severe pectus carinatum.

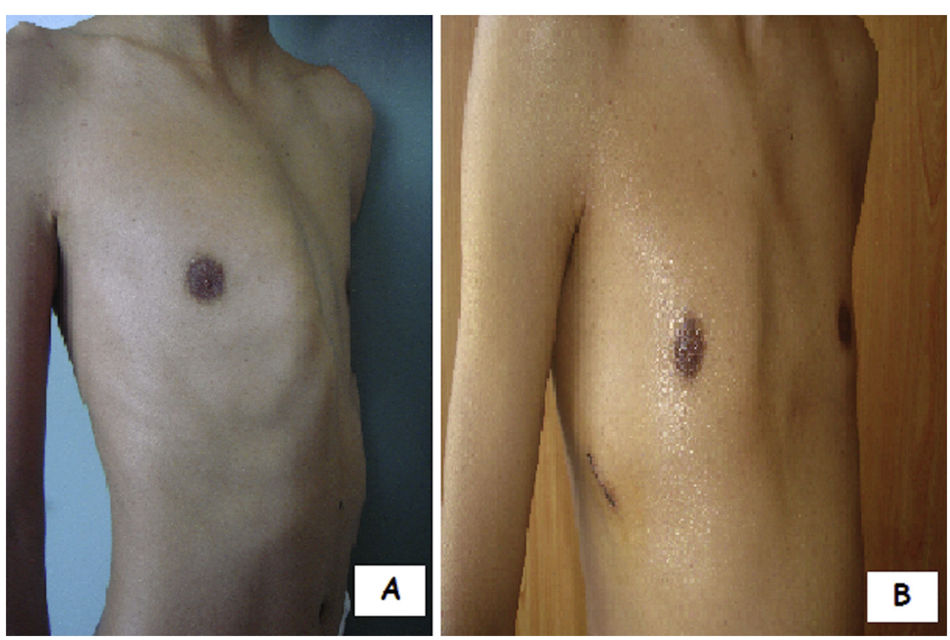
follow-up. Follow-up of at least 24 months after bar removal is necessary for recurrence monitoring.

In addition to esthetic correction after the MIRPC operation, the psychosocial functioning of the patients with pectus carinatum deformity also improves. In a recent study of our group [12], we demonstrated that the MIRPC operation has a positive effect on quality of life of patients. At 6 months postoperatively, psychosocial and physical functioning of the patients were both significantly improved, which was also supported by parental assessment.

The bar and the stabilizer system used in our cohort is different from the configuration reported by Abramson and colleagues [14]. In the work of Abramson and colleagues, strong subperiosteal wires are used to attach the fixation plates to the ribs and screws are used to secure the bar to the fixation plates. In our bar model, we use sternal cables to secure the stabilizers to the ribs. Our bar has 6 holes along each tip, and as the bar slides into the stabilizers while applying manual pressure over the protruded sternum to achieve the desired chest, a clip is simply placed to the appropriate hole to hold the bar in place. This bar and stabilizer configuration provides the best configuration to avoid complications and achieve successful correction rates.

Our surgical technique differs from the surgical technique of Kalman [21]. Kalman's technique uses a long curved clamp to enter the thoracic cavity at the midaxillary line, which is advanced horizontally and medially to move out through the next intercostal space. A presternal subcutaneous tunnel is created over the sternal protrusion, and the bar is placed through this track and advanced into the left side of the chest parasternally. The tip of the bar is pulled out to the outer surface of the ribs. Then the bar is fixed to the lateral thoracic wall muscles. As stated, this technique involves entry to both thoracic cavities, passing the thoracic wall 4 times. Postoperative pain control was achieved using epidural analgesia or narcotic pain medications for 34 ± 14 hours [21]. In our cohort, a subperiosteal tunnelling technique around the

Fig 10. Photographs show a 17-year-old patient with asymmetric deformity (A) preoperatively and (B) postoperatively.



ribs is used to secure the stabilizers to the ribs. This may have decreased the need for epidural analgesia. Although Kalman operated on asymmetric patients, he recommended the Ravitch procedure other than the minimally invasive carinatum repair for severely asymmetric patients. We achieved successful results in 78 asymmetric patients (45.3%) who underwent MIRPC with our fourth-generation bar configuration.

The excellent results in 93.8% of patients after MIRPC is associated with a short hospital stay (mean, 3.7 days), short operating time (mean, 76.6 minutes), and mild postoperative pain. The other advantages of MIRPC are minimal blood loss, early return to work or school, and no anterior chest wall scarring. Our fourth-generation carinatum bar has advantages of better stabilization of the bar on the ribs by the clip and sternal cable systems, which is effective in repairing both symmetric and asymmetric carinatum deformities.

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References

1. Goretsky MJ, Kelly RE, Jr, Croitoru D, et al. Chest wall anomalies: pectus excavatum and pectus carinatum. Adolesc Med Clin 2004;15:455–71.
2. Robiscek F, Watts LT. Pectus carinatum. Thorac Surg Clin 2010;20:563–74.
3. Fokin AA, Robicsek F. Management of chest wall deformities. In: Franco KL, Putnam JB (eds). Advanced Therapy in Thoracic Surgery. 2nd ed. Ontario: BC Decker Inc; 2005:145–62.
4. Brochhausen C, Müller FK, Turail S, James Kirkpatrick C. Pectus carinatum-first ultrastructural findings of a potential metabolic lesion. Eur J Cardiothorac Surg 2012;41:705–6.
5. Fokin AA, Steuerwald NM, Ahrens WA, Allen KE. Anatomical, histologic, and genetic characteristics of congenital chest wall deformities. Semin Thorac Cardiovasc Surg 2009;21:44–57.
6. Shamberger RC. Congenital chest wall deformities. In: Grosfeld JL, O'Neill JA Jr, Coran AG, et al (eds). Pediatric Surgery. 6th edition. Philadelphia, PA: Mosby Inc; 2006:904.
7. Fonkalsrud EW. Surgical correction of pectus carinatum: lessons learned from 260 patients. J Pediatr Surg 2008;43:1235–43.
8. Haller JA, Kramer SS, Lietman SA. Use of CT scans in selection of patients for pectus excavatum surgery: a preliminary report. J Pediatr Surg 1987;22:904–6.
9. Koumbourlis AC. Pectus deformities and their impact on pulmonary physiology. Paediatr Respir Rev 2015;16:18–24.
10. Steinmann C, Krille S, Mueller A, et al. Pectus excavatum and pectus carinatum patients suffer from lower quality of life and impaired body image: a control group comparison of physiological characteristics prior to surgical correction. Eur J Cardiothorac Surg 2011;40:1138–45.
11. Knudsen MV, Grosen K, Pilegaard HK, Laustsen S. Surgical correction of pectus carinatum improves perceived body image, mental health and self-esteem. J Pediatr Surg 2015;50:1472–6.
12. Bostanci K, Ozalper MH, Eldem B, et al. Quality of life of patients who have undergone the minimally invasive repair of pectus carinatum. Eur J Cardiothorac Surg 2013;43:122–6.
13. Abramson H. A minimally invasive technique to repair pectus carinatum. Preliminary report. Arch Bronconeumol 2005;41:34–51.
14. Abramson H, D'Agostino J, Wuscovi S. A 5-year experience with a minimally invasive technique for pectus carinatum repair. J Pediatr Surg 2009;44:118–23.
15. Schaarschmidt K, Lempe-Sellin M, Schlesinger F, Jaeschke U, Polleichtner S. New Berlin-Buch "reversed Nuss," endoscopic pectus carinatum repair using eight-hole stabilizers, submuscular CO2, and presternal Nuss bar compression: first results in 35 patients. J Laparoendosc Adv Surg Tech A 2011;21:283–6.
16. Cohee AS, Lin JR, Frants FW, Kelly RE, Jr. Staged management of pectus carinatum. J Pediatr Surg 2013;48:315–20.
17. Yuksel M, Bostanci K, Evman S. Minimally invasive repair of pectus carinatum using a newly designed bar and stabilizer: a single-institution experience. Eur J Cardiothorac Surg 2011;40:339–42.
18. Ravitch MM. The operative correction of pectus carinatum (pigeon breast). Ann Surg 1960;151:705–14.
19. Fonkalsrud EW, Beanes S. Surgical management of pectus carinatum: 30 years' experience. World J Surg 2001;25:898–903.
20. Shamberger RC, Welch KJ. Surgical correction of pectus carinatum. J Pediatr Surg 1987;22:48–53.
21. Kalman A. Initial results with minimally invasive repair of pectus carinatum. J Thorac Cardiovasc Surg 2009;138:434–8.
22. Emil S, Laberge JM, Sigalet D, Baird R. Pectus carinatum treatment in Canada: current practices. J Pediatr Surg 2012;47:862–6.
23. Katrancioglu O, Akkas Y, Karadayi S, Sahin E, Kaptanoğlu M. Is the Abramson technique effective in pectus carinatum repair? Asian J Surg 2018;41:73–6.
24. Varela P, Torre L. Thoracoscopic cartilage resection with partial perichondrium preservation in unilateral pectus carinatum preliminary results. J Pediatr Surg 2011;46:263–6.
25. Emil S, Sevigny M, Montpetit K, et al. Success and duration of dynamic bracing for pectus carinatum: a four-year prospective study. J Pediatr Surg 2017;52:124–9.