Ten-year experience with the muscle split technique, bioabsorbable plates, and postoperative bracing for correction of pectus carinatum: The Innsbruck protocol

Barbara Del Frari, MD, and Anton H. Schwabegger, MD, MSc

Objective: We reviewed further clinical experience with our approach for pectus carinatum repair: modified surgical approach of pectoralis muscle split technique, bioabsorbable plates with screws, and postoperative compressive brace.

Methods: From April 2000 to February 2010, 55 patients underwent pectus carinatum repair at our department with modifications of conventional Ravitch repair. There were 14 female and 41 male patients, mean age of 19.3 years at the onset of treatment. Postoperative treatment involved fitting of a lightweight, patient-controlled chest brace.

Results: Average follow-up was 13.7 months. Patient satisfaction was excellent for 40 patients (72.7%) and good for the remaining 15 (27.3%); aesthetic appearance was excellent for 37 patients (67.3%) and good for the remaining 18 (32.7%). Postoperative evaluation was objective measurement with a thorax caliper and clinical examination. No major perioperative complications were observed. Postoperative complications were mild recurrence of deformity (n = 3) and persistent, mild, single costal cartilage protrusion (n = 2). No patient had palpable plates or screws, and there was no material breakdown.

Conclusions: The combination of muscle split technique and absorbable osteosynthesis represents an alternative in pectus carinatum repair. The pectoralis muscle split technique allows early patient mobilization and rehabilitation. Bioabsorbable plates get completely absorbed, avoiding second operation, and chest brace provides postoperative immobilization of the anterior thoracic wall during healing and avoids development of hypertrophic scars. Our combined approach to the correction of pectus carinatum deformities yields predominantly excellent esthetic results, with low morbidity, low costs, and less invasiveness, leading to high patient satisfaction. (*J Thorac Cardiovasc Surg* 2011;141:1403-9)

Pectus carinatum (PC) is the protrusion of the sternum as a result of relative overgrowth of the costal cartilage. The overall prevalence of PC is 0.6%, and it is more common among men.¹ More than 26% of patients with PC have familial occurrence of pectus deformities.¹ PC may occur as a solitary abnormality or in association with other genetic disorders or syndromes (eg, trisomy 18, Marfan syndrome, homocystinuria, Morquio syndrome, and Ehlers–Danlos syndrome).² PC is often asymmetric, with significant rotation of the sternum.³ The most frequent type (chondrogladiolar) consists of anterior displacement of the mid and lower part of the sternum (gladiolus) and attached costal cartilages and is usually first recognized during early adolescence. Least common is the expression of upper chondromanubrial prominence with protrusion of the

manubrium, upper sternum, and adjacent cartilages. Symptoms in most patients are vague and vary from retarded growth, exertional dyspnea, or chronic dyspnea to asthmatic attacks and palpitations.⁴ Patients usually are disturbed by the appearance of the chest rather than by any functional difficulties.⁵

The traditional surgical repair of PC has involved resection of the abnormal costal cartilages, including 1 or several sternum osteotomies, with or without strut placement.^{6–8} Despite the established success of surgical correction of PC reported in the literature, the optimal age for repair with a surgical procedure most suitable to achieve optimal results still remains an issue of discussion. This report reviews further clinical experience now encompassing the past 10 years within a single institution, adopting a surgical approach that contains 3 modifications: the muscle split technique, bioabsorbable materials, and postoperative compressive bracing.^{9,10} These modifications are intended to enhance the final aesthetic outcome.

MATERIALS AND METHODS

During the 10-year period from April 2000 to February 2010, a total of 55 patients (41 men and 14 women) underwent a modified surgical correction of PC at our institution. The age at the time of surgery ranged from 14 to 49 years (mean, 19.3 years).

From the Department of Plastic, Reconstructive and Aesthetic Surgery, Medical University Innsbruck, Austria.

Disclosures: Authors have nothing to disclose with regard to commercial support. Received for publication June 21, 2010; revisions received Jan 27, 2011; accepted for publication Feb 22, 2011; available ahead of print April 1, 2011.

Address for reprints: Barbara Del Frari, MD, Department of Plastic, Reconstructive and Aesthetic Surgery, Innsbruck Medical University, Anichstraße 35, A-6020 Innsbruck, Austria (E-mail: Barbara.Del-Frari@i-med.ac.at).

0022-5223/\$36.00

Copyright © 2011 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2011.02.026

Abbreviation and Acronym

PC = pectus carinatum

Thirty-five of the 55 patients (63.6%) had an asymmetric deformity (Figure 1, A and B), 16 (29.1%) had a symmetric deformity, and pectus arcuatum (combination of PC and pectus excavatum) was present in 4 patients (7.3%). Seven patients showed a variety of associated medical disorders, including Poland syndrome (n = 2), scoliosis (n = 2), situs inversus (n = 1), incomplete cleft sternum (n = 1), and Recklinghausen disease (n = 1). Three patients had undergone previous heart operation.

Chest radiographs for all patients showed an increased anteroposterior diameter of the chest. In certain extensive cases and cases with malrotation of the sternum, a preoperative 3-dimensional volume-rendering mode computed tomographic scan was also performed for improved depiction of the skeletal deformity (Figure 2).¹⁰ Such a 3-dimensional radiologic image, with the capability of visualization in several planes, represents a helpful tool to design an exact treatment plan through the identification of important characteristics of complex deformities.

The evaluation of the surgical outcome consisted of preoperative and postoperative measurements of the horizontal and vertical chest diameters and clinical examination. For the purpose of objective noninvasive measurement, we used a thorax caliper first introduced in October 2003 (MedXpert Company GmbH, Heitersheim, Germany). For standardized measurement of the horizontal chest diameter, the ends of the caliper were placed at the level of the nipples along the right and left midaxillary line. For sagittal measurement, the caliper ends were positioned at the highest point of the sternum and at the corresponding processus spinosus of the thoracic vertebral body lying at the sagittal axis to the deformity. Improvement of the deformity was rated by caliper measurement of reduction of the external protrusion, subjective patient opinion, surgeon's appraisal of appearance, and photographic documentation. Items specifically screened for on the clinical examination included wound healing, signs of infection, and palpability of the implant through the skin, as well as visibility of residual or recurrent deformity. Bioabsorbable plates and screws were used in 29 patients because of asymmetric or extensive expression of deformities necessitating additional stabilization apart from the reefing sutures. The esthetic result was evaluated by an independent surgeon and by the subjective patient satisfaction.

Surgical Technique

Usually, a presternal midline vertical single incision is placed in men, whereas a bilateral incision along the submammary crease is preferred in women. In patients with asymmetric PC with solely unilateral expression of the deformity, a single incision may be placed horizontally above or remote from the deformity to deflect surgically produced scarring. Skin flaps are mobilized, and the parasternal area of the pectoralis major muscle surface is exposed. In contrast to the conventional technique, instead of major elevation of pectoralis major muscle flaps, the muscle is split along the direction of its fibers right above each rib, necessitating resection (Figure 3).⁹ After retraction of the muscle margins, subperichondrial resection of the costal cartilages is carried out (Figure 4). A transverse osteotomy, if needed for chest remodeling and depending on the type of deformity, is usually made across the anterior table and the spongiosa of the sternum. The posterior table commonly is left intact, but it is gently fractured, and then the inferior part sternum is lowered to the desired level. Only in cases with major malrotation of the sternum along the longitudinal axis does the posterior table of the sternal bone also need to be transected to enable it to twist into a frontal plane. After osteotomy and remodeling of the mobilized sternal part to the desired position, the sternum is stabilized with bioabsorbable plates and screws (polylactide copolymer BioSorbFX O/M; Bionx Implants Ltd, Tampere Finland), which are placed beneath the sternum

periosteum. From 2 to 4 plates, depending on the severity of the deformity and required number of osteotomies, each with a thickness of 1.4 mm and a length of 40 to 60 mm, and screws of 2.4×10 to 12 mm are set along a longitudinal axis to refix the osteotomized bones (Figure 5). The empty perichondrium tubes then are shortened with absorbable reefing sutures (1-0 polydioxanone) to secure the remodeling procedure and tighten the anterior chest wall. The split muscle fibers are gently adapted with absorbable sutures. A drain is inserted across the sternum. The skin is closed with subcuticular absorbable sutures. A circumferential elastic tape is used for initial compressive dressing.

Perioperative antibiotic is given intravenously as single dose or for 72 hours in cases with extensive remodeling. Postoperative pain is controlled with intravenous analgesics for the first 48 hours and by oral medications thereafter. Epidural analgesia is not used routinely except in complex cases.

Beginning with the third postoperative day, the elastic tape is replaced with an individually manufactured, custom-made, lightweight aluminum keel chest brace with a silicone-covered paddle for at least 23 hours per day for 6 to 8 weeks postoperatively (Figure 6, A and B). Patients are advised to sleep on the back postoperatively as long as wearing of the brace is necessary. The fitting of the brace was controlled after 1 week. Further controls depended on the comfort of carrying or development of skin irritation.

RESULTS

No major complications were observed in the perioperative period. We encountered 2 minimal intraoperative pleura lesions, both of which were immediately sutured during temporary elevation of ventilation pressure. One patient had meningitis caused by cutaneous bacteria developed postoperatively 2 days after explantation of the peridural catheter. Postoperative complications included mild recurrence of deformity (n = 3) caused by postoperative non-compliance in wearing the brace, persistent mild costal protrusion of 1 or 2 costal cartilages (n = 2), and pain caused by nonunion of a single rib cartilage (n = 1). The affected patients underwent minor surgical revision with resection of the localized persistent costal cartilage protrusion. Two patients had minor delays in wound healing, and 2 patients had decubitus formation, necessitating adjustment of the brace pressure. There were no cases of wound infection, wound seroma, or pneumothorax. The mean length of hospitalization was 8.2 days (5–12 days). Patients were discharged only after removal of the drains (<20 mL/d drainage). Customizing and fitting the brace can take several days and is still routinely controlled on an inpatient basis, because most of our patients live rather remotely from the hospital. No patient needed readmission after discharge excepts for those who required secondary corrections later on (after 1 year of follow-up) to refine persistent minor rib humps. We have obtained excellent results in a mean 13.7-month follow-up period (range, 4 months to 4.3 years). Patient satisfaction was excellent in 40 cases (72.7%) and good in the remaining 15 (27.3%), and the aesthetic appearance was excellent in 37 cases (67.3%) and good in the remaining 18 (32.7%). There was no dissatisfaction reported by any patient, with all patients reporting improvement in subjective body image (Figure 7, A and B).

FIGURE 1. A, Preoperative frontal view displaying the pectus carinatum of a 16-year-old patient. B, Right oblique view of the same patient.

The postoperative objective noninvasive measurement of the transverse and sagittal chest diameters in 27 patients (the thorax caliper has been in use since 2003) showed a mean reduction of the vertical chest diameter of 3.8 cm (range, 1–9 cm; Table 1).

With the muscle split technique, all patients resumed full range of passive and active motion of the upper extremities with exercise as early as 3 weeks postoperatively. Without strain, full movement was allowed as early as the first postoperative days, depending on the subjective well-being and individual perception of pain of the patients. The muscle split technique reduced the rehabilitation period. Excellent sternal stability was also obtained by using bioabsorbable plates and screws and bioabsorbable reefing sutures for

the perichondrium in the 29 cases in which sternum osteosynthesis was needed. At follow-up, none of these patients had palpable plates or screws, and there was no breakdown of any material. Furthermore, there were no infections and no discomfort related to the bioabsorbable material.

Because of the postoperative pressure therapy with the keel chest brace, we did not see any hypertrophic scar formation. The predominant purpose of the brace was to provide further stability and continuous compression to the area of remodeling. In addition, the use of the silicone surface at the compression pad was supportive to prevent hypertrophic scarring. Minor hypertrophy or enlargement of the cutaneous scar occurred in only 3 patients (2 of these patients were not compliant with therapy and 1 had mild wound dehiscence). In 1 of these cases, a scar revision was performed during minor surgical revision of a persistent protrusion of a single costal cartilage.

DISCUSSION

The ideal treatment of PC deformities is still subject to investigation and debate between nonsurgical and surgical methods.³ Many procedures have been proposed through the years, and each carries different advantages and disadvantages.^{2,3,7}

Preoperative chest imaging with computed tomography in selected cases helps to design a meaningful treatment program. Especially in the case of patients with an extensive deformity or malrotation of the sternum, a preoperative 3-dimensional volume-rendering mode computed tomographic scan is recommended.¹⁰ Importantly, the extent of malrotation and the number of associated deformed rib cartilages can be visualized, which allows exact preoperative planning of intended cartilage resection and localization of required sternum osteotomies.

The standard approach for correction of a PC deformity usually includes elevation of the pectoralis major and rectus abdominis muscles from the sternum and adjacent ribs, as

FIGURE 2. Preoperative 3-dimensional volume-rendering mode computed tomography.

FIGURE 3. Intraoperative view showing the splitting of the muscle along its fibers to expose the deformed rib. The parallel orientation allows longitudinal splitting of muscle for exposure of the rib cartilages without nerve transection.

FIGURE 4. Subperichondrial resection of the 5th costal cartilage on the left.

described by Ravitch.⁶ For 6 weeks postoperatively, the patient's physical activity at the shoulder girdle therefore is restricted to guarantee stable healing and reattachment of the muscle flaps.⁷ During the healing period, particularly for adult patients and especially for athletic male patients, such restricted immobilization may be necessary to prevent rupture of attachments, which can lead to a prolonged rehabilitation period. To minimize such postoperative immobilization, a modified approach to the parasternal ribs with the muscle split technique is performed, which means splitting of the pectoralis major and rectus abdominis muscle along the fibers to expose each individual rib without the need for extensive muscle flap elevation.¹⁰ Through preservation of muscle insertion and vascularization, the technique should allow the patient to resume postoperative activity much earlier than with conventional former flap elevation techniques. Patients return to full unrestricted shoulder activity as early as 3 weeks postoperatively, in contrast to 6 weeks for patients treated with muscle flap elevation.⁷ In our experience, the surgical time required for the modified technique does not differ essentially from that needed for the conventional technique. None of our patients

had development of abdominal muscle hernia or abdominal weakness. Such a potential complication, which has been reported by Schoenmakers and colleagues¹¹ and by Luzzi and associates,¹² may be attributed to weakness of the rectus muscle resulting from its disconnection from the lower costal arches at the anterior chest wall within the conventional approach. This is no issue at all in the pure muscle splitting technique.

Fonkalsrud and colleagues⁸ in 2004 described a modification of the Ravitch technique in a series of 154 patients, suggesting the use of a temporary stainless steel support bar anterior to the sternum and cartilage for 6 months. This bar was secured to the appropriate rib on each side with fine wires. In their opinion, the bar provides stability to the chest wall during the period of costal cartilage regeneration and eliminates development of recurrent sternal protrusion. Fonkalsrud and coworkers¹³ reported the use of this sternal support in 1994. Kálmán and colleagues¹⁴ have described the use of a steel bar for correction of PC deformities in 14 patients. An important drawback, however, is that this bar must be removed in a second operation, and moreover the bar may interfere with computed tomographic or magnetic resonance imaging evaluation.

FIGURE 5. Stabilization of the sternum after transverse osteotomy with bioabsorbable plates and screws.

Matsui and associates¹⁵ described the use of large and bulky bioabsorbable poly-L-lactide struts for the treatment of pectus excavatum, and Gürkök and colleagues¹⁶ reported the use of large bioabsorbable copolymer plaques and screws for the correction of pectus excavatum. They

described a new technique adopted in 33 patients for fixing the sternum at the level of the wedge osteotomy in pectus excavatum, with no recurrences in the follow-up of 1 year. Such voluminous foreign-body implants, however, are not desirable in the correction of keel chest deformities, because they are bulky, palpable, and need extensive elevation of the periosteum. This prompted us to use smaller bioabsorbable materials for the sternum osteosynthesis, already well-established in such applications as craniofacial surgery.¹⁷ Bioabsorbable fixation devices are increasingly being used in trauma and in orthopedic and cranio-maxillo-facial surgery, and they have even been proved to be safe for use in children.¹⁸ Because these implants are completely absorbed, they obviate the need for a removal operation and avoid long-term interference with the growing skeleton. As the plates are absorbed, stress loads are gradually retransferred to the bone.¹⁹ Reabsorption of copolymer plaques and screws is usually complete by the end of the first year,¹⁷⁻¹⁹ and these implants advantageously do not interfere with clinical imaging.

Mansour and coworkers²⁰ in 2003 reported good results by using strong nonabsorbable sutures placed through the right and left sides of the xiphoid and around the second rib bilaterally, tightening the xiphoid attachment to the rectus muscles beneath the sternum. Their retrospective review, performed on 77 patients, included only 9 patients (11.7%) with PC only, and it cannot be determined from their article whether that suture was used in the treatment of PC, pectus excavatum, or both, nor is it clear what the permanent results in the PC collective were.

A nonoperative approach with a dynamic chest compressor orthosis was first proposed by Haje and Bowen²¹ in 1979 and by others.² To our knowledge, the adjuvant use of such bracing after surgical correction of PC, except in our own previous publications,^{9,10} has not yet been described elsewhere. Progressing from our previous publication in

FIGURE 6. A, Individually manufactured, custom-made lightweight aluminum keel chest brace with a silicone-covered front on a 15-year-old patient. B, Pressure therapy with the keel chest brace worn by a 19-year-old woman.

FIGURE 7. A, Frontal view at 3 years postoperatively after correction of the pectus carinatum. B, Right oblique view at 3 years postoperatively. Final result.

2008,⁹ we have extended the indication for this modified surgical approach to older patients, patients with asymmetric deformities, and patients with other medical disorders. Minor hypertrophy or enlargement of the cutaneous scar occurred in only 3 patients in our series (5.5%). This finding is in sharp contrast to the data reported by Fonkalsrud and

Beanes⁷ of a 14.5% rate of hypertrophic scarring in their series that did not use such a compression brace.

CONCLUSIONS

Our experience with the integrative concept of the muscle splitting technique, absorbable osteosynthetic material, and

TABLE 1. Preoperative and postoperative objective noninvasive measurements of the sagittal chest diameter with the thorax caliper

Case	Sex	Age (y)	Follow-up (mo)	Sagittal chest diameter (cm)		
				Preoperative	Postoperative	Postoperative reduction
1	Male	19	25	27	20	7
2	Female	14	26	24	20	4
3	Female	19	32	26	18	8
4	Male	16	12	16	15	1
5	Female	31	31	24	18	6
6	Male	17	32	20.5	17	3.5
7	Male	16	11	21	18	3
8	Male	16	8	22	18	4
9	Male	16	12	24.5	16	8.5
10	Female	25	18	26	17	9
11	Male	20	4	23	18	5
12	Male	16	12	20	18.5	1.5
13	Female	22	6	20	17.5	2.5
14	Male	18	12	20	18.5	1.5
15	Male	16	13	24.5	20.5	4
16	Male	14	12	18	17	1
17	Male	15	7	19.5	18	1.5
18	Female	26	12	22	18	4
19	Male	18	12	21	19	2
20	Male	15	12	22	18	4
21	Female	16	12	21.5	20	1.5
22	Female	22	7	21	18	3
23	Female	16	6	20	15	5
24	Female	17	12	18	16	2
25	Male	23	9	18	16.5	2.5
26	Male	17	7	20.5	18	2.5
27	Male	15	13	20	16	4

postoperative bracing in combination with the skeletal remodeling steps according to Ravitch allows us to suggest this procedure as an treatment option. Additional results now upgrade our previously published experiences with the muscle split technique as an alternative to the conventional muscle flap elevation technique in the correction of PC deformities. In our opinion, postoperative bracing is to be preferred as an important adjunct in improving the final esthetic outcome by providing pressure therapy to avoid hypertrophic scar formation.

We thank Beata Seeber, MD, Department of Obstetrics and Gynecology, Medical University Innsbruck, Innsbruck, Austria, for assistance with editing the English language of this article.

References

1. Shamberger RC, Welch KJ. Surgical correction of pectus carinatum. *J Pediatr Surg.* 1987;22:48-53.
2. Kravarsic D, Dicken BJ, Dewar R, Harder J, Poncet P, Schneider M, et al. The Calgary protocol for bracing of pectus carinatum: a preliminary report. *J Pediatr Surg.* 2006;41:923-6.
3. Stephenson JT, Du Bois J. Compressive orthotic bracing in the treatment of pectus carinatum: the use of radiographic markers to predict success. *J Pediatr Surg.* 2008;43:1776-80.
4. Robicsek F, Sanger PW, Taylor FH, Thomas MJ. The surgical treatment of chondrosternal prominence (pectus carinatum). *J Thorac Cardiovasc Surg.* 1963;45:691-701.
5. Garcia VF, Seyfer AE, Graeber GM. Reconstruction of congenital chest-wall deformities. *Surg Clin North Am.* 1989;69:1103-18.
6. Ravitch MM. The operative correction of pectus carinatum (pigeon breast). *Ann Surg.* 1960;151:705-10.
7. Fonkalsrud EW, Beanes S. Surgical management of pectus carinatum: 30 years' experience. *World J Surg.* 2001;25:898-903.
8. Fonkalsrud EW, Anselmo DM. Less extensive techniques for repair of pectus carinatum: the undertreated chest deformity. *J Am Coll Surg.* 2004;198:898-905.
9. Schwabegger AH, Jeschke J, Schuetz T, Del Frari B. Refinements in pectus carinatum corrections: the pectoralis muscle split technique. *J Pediatr Surg.* 2008;43:771-4.
10. Schwabegger AH, Harpf C, Ninkovic M, Rieger M. Technical refinements in planning and surgical therapy of pectus carinatum [in German]. *Chirurg.* 2002;73:1191-6.
11. Schoenmakers M, Gulmans V, Bax N, Helders P. Physiotherapy as an adjuvant to the surgical treatment of anterior chest wall deformities: a necessity? A prospective descriptive study in 21 patients. *J Pediatr Surg.* 2000;35:1440-3.
12. Luzzi L, Voltolini L, Zacharias J, Campione A, Ghiribelli C, Di Bisceglie M, et al. Ten year experience of bioabsorbable mesh support in pectus excavatum repair. *Br J Plast Surg.* 2004;57:733-40.
13. Fonkalsrud EW, Salman T, Guo W, Gregg JP. Repair of pectus deformities with sternal support. *J Thorac Cardiovasc Surg.* 1994;107:37-42.
14. Kálmán A. Initial results with minimally invasive repair of pectus carinatum. *J Thorac Cardiovasc Surg.* 2009;138:434-8.
15. Matsui T, Kitano M, Nakamura T, Shimizu Y, Hyon SH, Ikada Y. Bioabsorbable struts made from poly-L-lactide and their application for treatment of chest deformities. *J Thorac Cardiovasc Surg.* 1994;108:162-8.
16. Gürkök S, Genç O, Dakak M, Balkanlı K. The use of absorbable material in correction of pectus deformities. *Eur J Cardiothorac Surg.* 2001;19:711-2.
17. Ashammakhi N, Peltoniemi H, Waris E, Suuronen R, Serlo W, Kellomäki M, et al. Developments in craniomaxillofacial surgery: use of self-reinforced bioabsorbable osteofixation devices. *Plast Reconstr Surg.* 2001;108:167-80.
18. Eppley BL. Use of resorbable plates and screws in pediatric facial fractures. *J Oral Maxillofac Surg.* 2005;63:385-91.
19. Mayberry JC, Terhes JT, Ellis TJ, Wanek S, Mullins RJ. Absorbable plates for rib fracture repair: preliminary experience. *J Trauma.* 2003;55:835-9.
20. Mansour KA, Thourani VH, Odessey EA, Durham MM, Miller JJ Jr, Miller DL. Thirty-year experience with repair of pectus deformities in adults. *Ann Thorac Surg.* 2003;76:391-5.
21. Haje SA, Bowen JR. Preliminary results of orthotic treatment of pectus deformities in children and adolescents. *J Pediatr Orthop.* 1992;12:795-800.