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ORIGINAL ARTICLE

Amulya K. Saxena
Klaus Schaarschmidt
Jürgen Schleef
Jose J. Morcate
Günter H. Willital

Surgical correction of pectus excavatum: the Münster experience

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A. K. Saxena (✉) · K. Schaarschmidt
J. Schleef · J. J. Morcate · G. H. Willital
Klinik für Kinder- und Neugeborenenchirurgie,
Westfälische-Wilhelms Universität,
Albert Schweitzer Strasse 33,
D-48129 Münster, Germany
(Tel.: +49-251-8347723,
Fax: +49-251-8348045)

Abstract *Objectives:* Pectus excavatum is the most common congenital hereditary chest-wall deformity. This study analyses a single-center experience of pectus excavatum–thoracic wall reconstruction using a uniform technique of internal stabilization employing stainless steel struts. *Methods:* From June 1984 to December 1997, we performed correction operations on 777 patients with pectus excavatum. The condition occurred more frequently in boys (621 patients) than girls (156 patients). Surgical repair was performed using a standard method of double bilateral chondrotomy parasternally and at points of transition to normal ribs. This was followed by detorsion of the sternum, retrosternal mobilization and correction of the inverted ribs. The anteriorly displaced sternum was stabilized by one trans-sternal and two bilateral parasternal metal struts. *Results:* The corrections were completed with successful repair in 765 patients (98.5%) with a low complication rate of 6.7%. The follow-up period ranged from 4 weeks to 12 years, mean 6.4 years. Major recurrences were observed in 12 patients (1.5%) and mild recurrence were observed in 35 patients (4.5%). *Conclusion:* Significant reduction in postoperative cardiorespiratory disorders, low lethality, improvement of subjective complaints, satisfactory long-term results and improvement in psychological problems indicate the need to offer this method of surgical correction to low-risk children.

Key words Pectus excavatum · Funnel chest · Surgery

Introduction

Pectus excavatum (funnel chest), a depression deformity of the chest wall, was first reported by Bauhinus in 1594 [1] and was described again later by Eggel in 1870 [2]. Meyers in 1911 [3] and Sauerbruch in 1913 [4] reported the earliest surgical repair of this deformity. Ochsner and DeBakey [5] reviewed the early experiences with repair in 1938. Analysis of the clinical problem and description of a simplified operative technique by Brown in 1939 [6] initiated the trend of modern surgical management. Ravitch [7] reported, in 1949, of a technique involving the excision of all deformed cartilages, with anterior fixation of the sternum using Kirschner wires and silk sutures. In addition, Hegemann's report of surgical management with metal struts to stabilize the sternum, in 1965 [8], laid the foundation for the present techniques practiced worldwide.

The incidence of funnel chest is 1 in 1000 live births with a 3:1 male-female predominance [9]. Although it appears that the vast majority of instances are sporadic [10], familial incidences have been frequently documented. An autosomal dominant inheritance accounts for the genetic predisposition of this deformity [11]. However, acquired chest depression deformities secondary to cardiac surgery have also been observed at our center. Musculoskeletal abnormalities, most frequently scoliosis, are associated with pectus excavatum, and may not require surgical evaluation.

Table 1 Willital's classification of congenital chest-wall deformities

Type	Description
1	Symmetric pectus excavatum within a normal configured thorax
2	Asymmetric pectus excavatum within a normal configured thorax
3	Symmetric pectus excavatum associated with platythorax
4	Asymmetric pectus excavatum associated with platythorax
5	Symmetric pectus carinatum within a normal configured thorax
6	Asymmetric pectus carinatum within a normal configured thorax
7	Symmetric pectus carinatum associated with platythorax
8	Asymmetric pectus carinatum associated with platythorax
9	Combination of pectus excavatum and pectus carinatum
10	Thoracic wall aplasia
11	Cleft sternum

The severity of the deformity is extremely variable. Chest-wall depression is well tolerated in infancy; however, many older children report subjective complaints such as dyspnea, cardiac dysesthesia and limited work performance. Surgical correction has been performed in many centers mainly for esthetic and psychological reasons; however, compression and secondary changes of the intrathoracic organs have been indications for surgery.

Classification

Our patients were graded according to the Willital's classification, which is based on morphologic findings of the thorax and divides congenital chest-wall deformities into 11 types – funnel chest (4 types), pigeon chest (4 types), combination of funnel and pigeon chest, chest-wall aplasia and cleft sternum (Table 1) [12]. This classification allows assessment of the operation technique with regard to the location of implantation of the metal struts, as well as the determination of the number of struts to be used for internal stabilization of the chest wall [13]. Examination of 777 pectus excavatum patients preoperatively showed that 32% have a depression deformity with a symmetrical chest wall (Fig. 1). These patients have the best prognosis after surgical reconstruction in comparison with the other forms.

Materials and methods

At the Pediatric Surgical University Clinic, Münster, we performed 902 surgical corrections on patients with congenital chest-wall deformities from June 1984 to December 1997. Thoracic reconstruction operation for funnel-chest-type deformity was performed on 777 patients during this 13-year period; 125 patients were operated on for the remaining 7 types of chest deformities. Pectus excavatum occurred more frequently in boys (621 patients) than girls (156 patients). The defect was evident within the first year of life in the majority of the patients (82%).

Surgical technique

Our standard technique employs stainless steel struts for the correction of the deformity. A vertical midline incision is made in boys; in girls, a sub-mammary incision, which

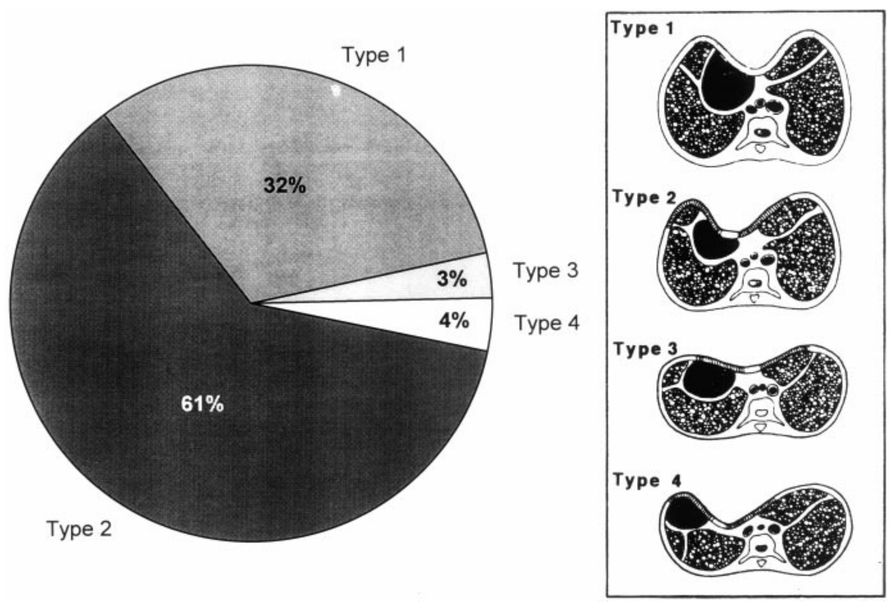

Fig. 1 Percentile distribution of 777 patients operated on (1984–1997) and schematic representation of funnel chest (four types) according to Willital's classification of chest-wall deformities

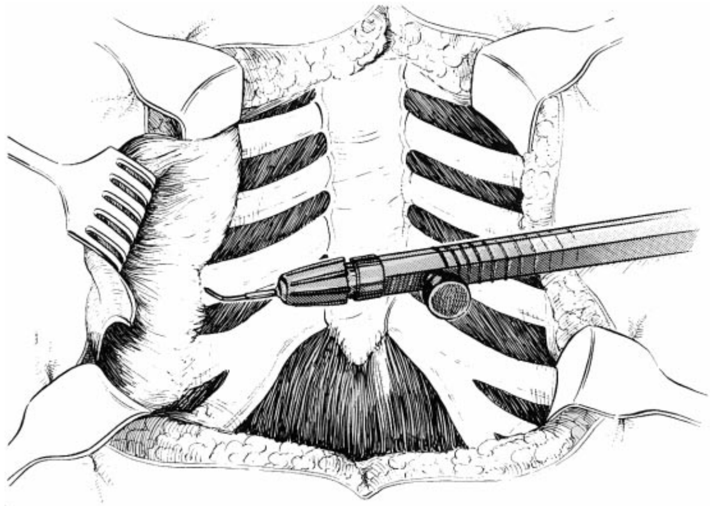

Fig. 2 En bloc dissection of the area of depression using electrocautery

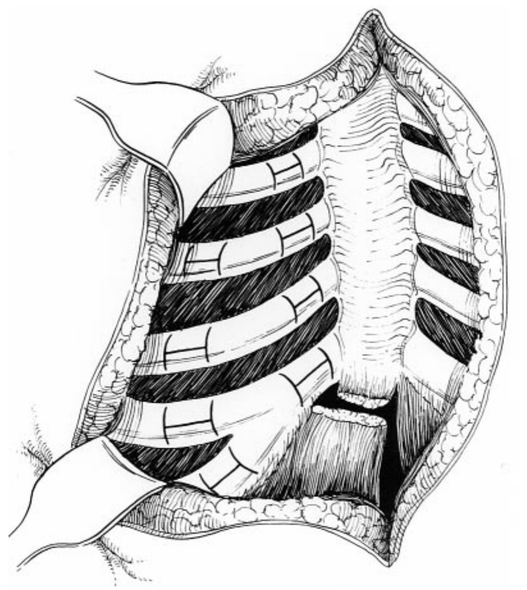

Fig. 3 "H"-form incision of the perichondrium parasternally and at points of transition to normal ribs

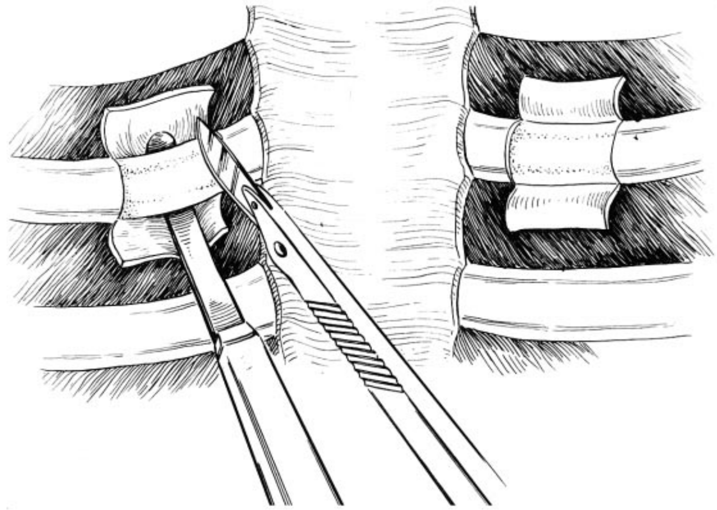

Fig. 4 Resection of cartilages using a knife with a perichondral elevator held posteriorly

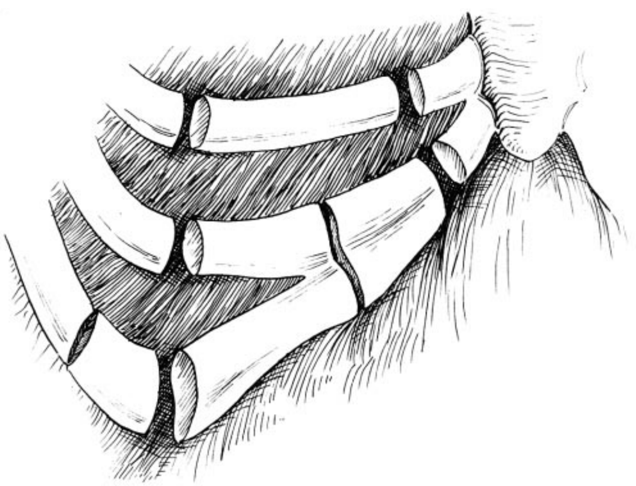

Fig. 5 Multiple incisions and resections of deformed lower costal cartilages

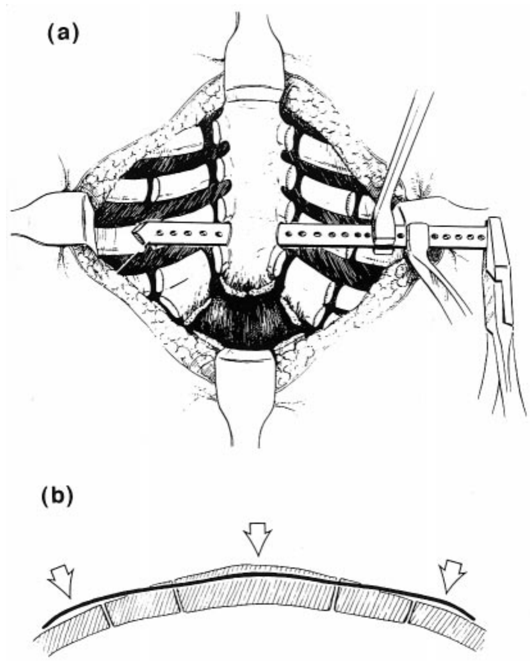

Fig. 6 **a** Stabilization of the mobile sternum with a trans-sternal metal strut. **b** The *arrows* indicate the points at which the metal strut is bent to fit corrected contours

is curved upward at the midpoint (over the deepest point of the sternal defect), is preferred, thus avoiding the complication of breast deformity and impaired breast development [14]. In the incision, skin, fat and pectoral muscles are reflected in a single flap and the entire dissection is performed with a needle-tipped electrocautery (Fig. 2). The pectoral muscles are severed from its insertion at the edge of the sternum and costal cartilages to expose the entire impression of the deformity, generally formed by five to eight pairs of ribs (third to tenth rib). When the deformed costal cartilages have been completely exposed, the perichondrium is incised with the needle-tip cautery in the form of an *H* (Fig. 3). The sub-perichondrial dissection is carried out with small, sharp periosteal elevators and the perichondrium is scraped away from the underlying cartilage (Fig 4). The deformed costal cartilages are resected parasternally from their junction with the rib to within 1 cm of the sternum as well as at the level of transition to the normal ribs, leaving the uppermost normal cartilages intact (Fig. 5).

The attachment of the rectus muscle to the sternum is severed, and the sternum is elevated with a Kocher clamp and dissected free from the anterior mediastinal tissue after retrosternal mobilization. A partial transverse sternal-wedge osteotomy is performed at the Angle of Ludovici. Once the sternum is dissected free, as described, a perforated Hegemann steel strut (Lettenbauer, Erlangen, Germany) is passed trans-sternally, with its edges resting anteriorly on the ribs (Fig. 6). The strut must be bent in such a way that it fits the thorax wall perfectly at the edge of the impression. Two parasternal metal struts are also employed, with the points of fixation being the second rib and the lowest end of the rib cage (Fig. 7). The trans-sternal strut is fixed to the two parasternal struts with stainless steel wires for additional support. The two parasternal struts also provide anchorage to the completely mobile chest segments, which were formed as a result of double bilateral chondrotomy. Heavy resorbable suture material is then used to close the sternal osteotomy and to secure the struts to the chest wall. Two single-limb chest tubes are placed in parasternal positions at the level of the highest costal cartilage resection. The pectoral muscle flaps and the severed rectus muscles are then sutured and fixed to the sternum. The overlying subcutaneous and cutaneous structures are finally united in the conventional manner to restore the normal chest-wall anatomy.

Blood transfusion is rarely necessary. Perioperative antibiotic therapy is administered; ceftriaxon is the drug of choice. All patients are also administered strong analgesics for the first 24–72 h. The chest tubes are generally removed on the third day or when the drainage is less than 25 ml over a 12-h shift. Wound infections are rare and the patients are mobilized after chest-tube removal. On the fourth day, pulmonary exercises are commenced with Triflo II Respiratory Exerciser (Sherwood Medical, Schwalbach, Germany) and are continued for a period of 3 weeks. At the time of discharge, patients are advised to avoid body-contact sports until the struts have been removed. We encourage regular swimming and light athletic exercises and recommend physiotherapeutic exercises if necessary. The struts are removed after a period of 12 months in patients over 12 years, but are retained for 15–24 months in younger children, so as to stabilize the thorax that is still under the growth spurt.

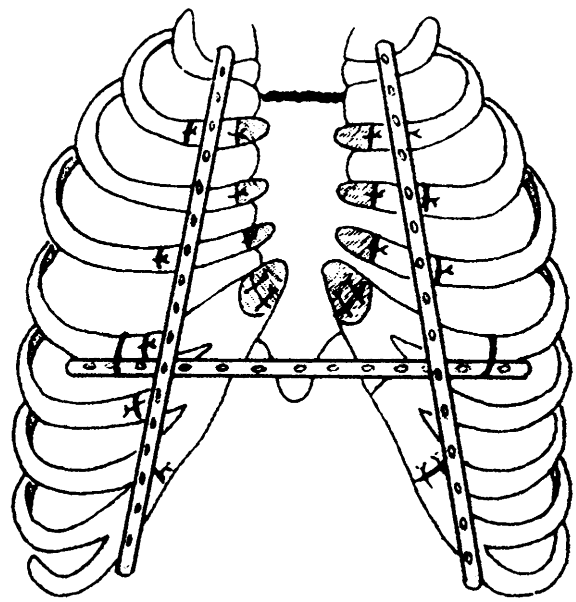

Fig. 7 Schematic overview of the operation technique showing strut placement

Table 2 Surgical complications after pectus excavatum repair

Complications	No. of patients
Serothorax	19
Pneumothorax	12
Wound dehiscence	8
Wound infection	4
Strut dislocation	4
Hemothorax	2
Wound hematoma	1
Osteomyelitis	1
Intraoperative cardiac arrest	1

Results

Most of the patients at the time of surgical correction were children (274 patients) in the 11-year to 15-year-old age group (Fig. 8). The postoperative course of 776 patients was generally uneventful and the repairs were completed with a complication rate of 6.7% (Table 2). One patient died intraoperatively due to cardiac arrest. Furthermore, postoperative recovery in children less than 12 years was 2–4 days; this

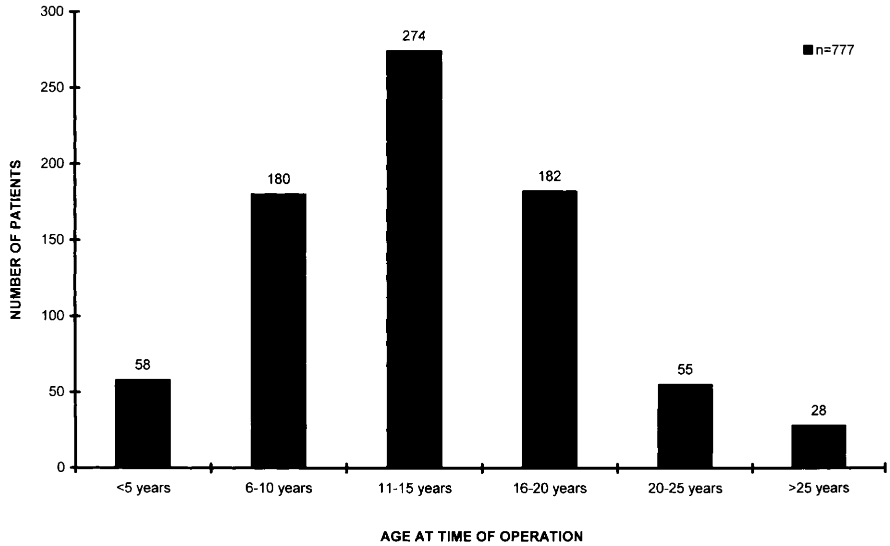

Fig. 8 Pectus excavatum; age at time of corrective surgery

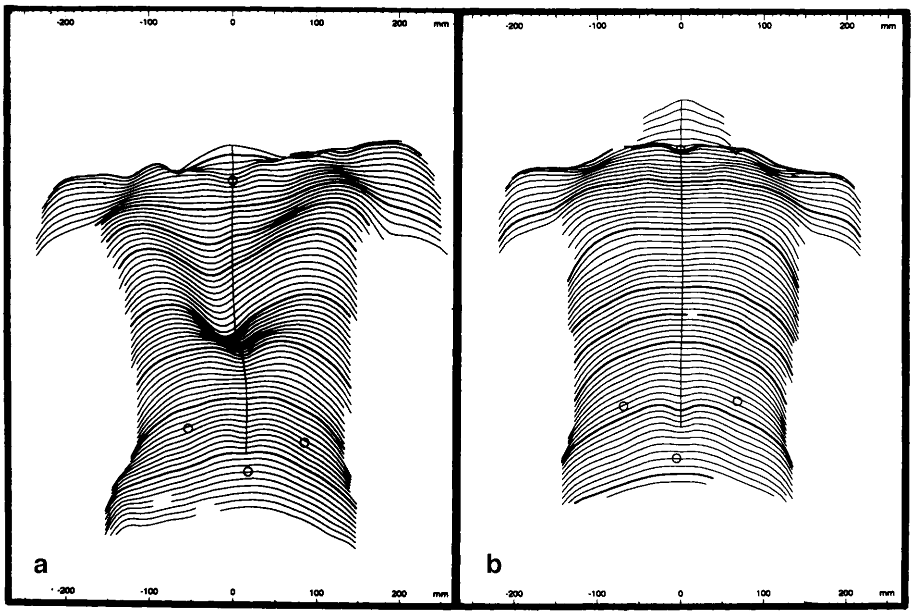

Fig. 9 a, b Chest-wall raster stereograph preoperatively (**a**) and after thoracic reconstruction (**b**)

was significantly faster than the 4–7 days that it took in teenagers and adults. Major recurrence was found in 12 patients (1.5%) and all of these patients were re-operated on. Minor recurrences we found in 35 patients (4.5%). Satisfactory long-term results were obtained in the rest of the patients. Struts were removed under general anesthesia and scars were revised in all the patients at the time of strut removal.

In 97% (754 patients) of all cases, the subjective complaints of the patients prior to surgery were eliminated at the time of follow-up examinations. Our follow-up period ranged from 4 weeks to 12 years (mean 6.4 years) and the documentation of the preoperative deformity as well as the status of surgical repair included: (1) measurement of the sagittal thorax diameter using a pelvimeter; (2) electrocardiogram; (3) pulmonary function tests in children more than 8 years of age; and (4) a clinical photograph. Ultrasonography was performed prior to discharge and during the first follow-up to rule out any intrathoracal fluid accumulations. Since 1994, our documentation has also included raster stereographs, which are routinely obtained to demonstrate the preoperative deformity and the result of repair (Fig. 9).

Discussion

Conservative measures or “wait-and-observe” strategy in patients referred to our center followed over the last 13 years never resulted in improvement of this deformity. There is no unanimity in the literature as to the best time of intervention or for the necessity for such an intervention [15]. However, surgery of funnel chest is easier to perform in children because the ribs are soft and easier to correct. Also, early correction allows the thoracic structures to develop normally before irreversible alterations set in. In our series of patients, operated on at ages of less than 12 years, we observed no increased correlation to recurrence or redeformation due to the growth spurt later in the adolescent stages. Furthermore, because of the faster postoperative recovery and since no observed disturbances in physiologic growth of the thorax is seen after surgery, we consider the best time for intervention to be during school age (8–12 years). However, in female patients, it is advisable to wait until the pubertal breast growth demarcates the sub-mammary line.

Mechanical factors, such as cardiac displacement due to the deformity, are responsible for the functional disturbances of the right and left sides of the heart in systole and diastole. This has been attributed to be more a disorder of compliance of the right side of the heart than the output of the ventricle. Decreased right-ventricular filling due to impaired function of the right atrium is also responsible for the reduced stroke volume during exercise [16]. Preoperative echocardiographic and Doppler findings have also correlated well with the extent of cardiac displacement [17]. A significant increase in the cardiac index after operation is evident when patients performed exercises in the sitting position, presumably on the basis of an increased stroke volume. A decrease in the heart rate at any given work performance after operation, evident as the improvement in exercise capacity, is due to the result of an increase in cardiac stroke volume and could explain the subjective circulatory stabilization experienced by the patients.

Restrictive impairment of pulmonary function, expressed by reduced total lung capacity and inspiratory vital capacity is found in patients with funnel chest [18–20], although normal functions have also been observed [21, 22]. Even after surgical correction of the deformity there is a significant reduction in the total capacity and inspiratory vital capacity of the lungs, probably a result of the decreased compliance of the chest wall [23, 24]. However, the efficiency of breathing (ratio of tidal volume/inspiratory vital capacity) at maximal exercise improves significantly after operation [16].

Lower rates of recurrence have been observed in many long-term studies after the correction of funnel chest [25–27]. Irrespective of the technique, we consider the main reasons for recurrence to be: (1) inadequate mobilization of the depressed chest wall (2) unstable fixation of the mobilized chest wall and (3) no or inadequate remodeling of the lowest parts of the deformed ribs [28]. Complete exposure of sternum and ribs is necessary for satisfactory results as it allows complete intraoperative assessment of the deformity and is of significant importance in patients more than 15 years of age who may require an additional trans-sternal strut because of the extensive area of sternal depression. This also allows placement of struts and stainless steel wires under complete vision and avoids serious complications, such as cardiac perforation [29].

Previously in our series, chest tubes placed during surgery were guided out through the umbilicus for esthetic reasons; to prevent additional thoracic scar formation. Inadequate draining of the intrathoracic space, due to loss of length of the chest tubes during supraumbilical transit, was responsible for the larger number of intrathoracic air and fluid accumulations. Postoperative abdominal distention due to peritoneal irritation was frequently observed as a result of supra-umbilical chest-tube transit. Since 1994, the chest tubes have been guided out through the intercostal space and a drastic reduction of these complications has been observed.

Intravenous pethidine (1 mg/kg) was administered as the analgesic of choice for pain control every 6 h for the first 24–72 h postoperatively. A tremendous improvement in pain control and the elimination of potential disadvantages of sedation and respiratory depression due to narcotic analgesics have been achieved by the introduction of continuous thoracic epidural infusions [30]. Since 1995, epidural catheters have been routinely placed preoperatively by the anesthesiologists at the T4–T10 level, after induction of general anesthesia. Bupivacaine is infused through epidural catheter pumps and supplemental narcotics are rarely required. In the eventuality of catheter displacement, narcotics are administered only after catheter removal, thus avoiding any complications that may arise as a result of excessive analgesic administration.

During the follow-up examinations, special attention must be paid to the standing and sitting posture of patients. Correcting the posture of patients, if required, using a figure-of-eight bandage, especially after the removal of metal struts, as well as regular exercises, such as light athletics and swimming in younger children, aerobic exercises in adolescent females and physical training in adolescent males, have been observed to be important external factors which have contributed positively to the maintenance of the reconstructed thorax. Small residual subsistent deformities can, however, be masked by the development of muscles in males, and breasts in females.

Conclusion

Our technique presents a rather radical approach to the repair of funnel-chest deformities using stainless steel struts for internal stabilization of the depressed thoracic segment. Satisfactory long-term results with a low rate of complication and improvement of subjective complaints renders this technique safe and effective for low risk patients.

References

1. Bauhinius J Schenck von Grafenberg, Johannes (1594) Observationum medicarum, rararum, novarum, admirabilium, et montrosarum, liber secundus. De partibus vitalibus, thorace contentis. Observation 264: 516
2. Eggel G (1870) Eine seltene Missbildung des Thorax. Virchows Arch 49: 230
3. Meyer L (1911) Zur chirurgischen Behandlung der angeborenen Trichterbrust. Verh Berliner Med 42: 364–373
4. Sauerbruch F (1920) Die Chirurgie der Brustorgane. Springer, Berlin Heidelberg New York, pp 440–444
5. Ochsner A, DeBakey M (1938) Chonechondrosteron: report of a case and review of the literature. J Thorax Surg 8: 469–511
6. Brown AL (1939) Pectus excavatum (funnel chest). J Thorac Surg 9: 164
7. Ravitch MM (1949) The operative treatment of pectus excavatum. Ann Surg 129: 429–444
8. Hegemann G, Leutschaft R (1965) Die operative Behandlung der Trichterbrust. Thoraxchirurgie 13: 281–287
9. Clausner A, Hoffmann-v Kapp-herr S (1995) Gegenwartiger Stand der Trichterbrust. Dtsch Med Wochenschr 120: 881–883
10. Ravitch MM (1977) Congenital deformities of the chest wall and their operative correction. Saunders, Philadelphia, pp 78–205
11. Leung AKC, Hoo JJ (1987) Familial congenital funnel chest. Am J Med Genetics 26: 887–890
12. Willital GH, Maragakis MM, Schaarschmidt K, et al (1991) Indikation zur Behandlung der Trichterbrust. Dtsch Krankenpfleger Zeitsch 6: 418–423
13. Willtal GH (1981) Operationsindikation-Operationstechnik bei Brustdeformierung. Z Kinderchir 33: 244–252
14. Hougaard K, Arendrup H (1983) Deformities of the female breasts after surgery for funnel chest. Scand J Cardiovasc Surg 17: 171–174
15. Goertzen M, Baltzer A, Schulitz KP (1993) Long-term results after operation for funnel chest. Arch Orthop Trauma Surg 112: 289–291
16. Morshius WJ, Folgering HT, Barentz JO, et al (1994) Exercise cardiorespiratory function before and one year after operation for pectus excavatum. J Thorac Cardiovasc Surg 107: 1403–1409
17. Clausner A, Clausner G, Basche S, et al (1991) Importance of morphological findings in the progress and treatment of chest wall deformities with special reference to the value of computer tomography, echocardiography and stereophotogrammetry. Eur J Pediatr Surg 1: 291–297
18. Wynn SR, Driscoll DJ, Ostrom NK, et al (1990) Exercise cardiorespiratory function in adolescents with pectus excavatum. J Thorac Cardiovasc Surg 99: 41–47
19. Cahill JL, Lees GM, Robertson HT (1984) A summary of preoperative and postoperative cardiorespiratory performance in patients undergoing pectus excavatum and carinatum repair. J Pediatr Surg 19: 430–433
20. Castille RG, Staats BA, Westbrook PR (1982) Symptomatic pectus deformities of the chest. Am Rev Respir Dis 126: 564–569
21. Derveaux L, Ivanoff I, Rochette F, et al (1988) Mechanism of pulmonary function changes after surgical correction for funnel chest. Eur Respir J 1: 382–385
22. Kaguraoka H, Ohnuki T, Itaoka T, et al (1992) Degree of severity of pectus excavatum and pulmonary function in preoperative and postoperative periods. J Thorac Cardiovasc Surg 104: 1483–1488
23. Derveaux L, Clarysse I, Ivanoff I, et al (1989) Preoperative and postoperative abnormalities in the chest X-ray indices and in the lung function in pectus deformities. Chest 95: 850–856
24. Gimeno F, Eijgelaar A, Peset R (1984) Lung function changes after operation for pectus excavatum and carinatum. Bull Eur Physiopathol Respir 20: 17A
25. Shamberger RC, Welch KJ (1988) Surgical repair of pectus excavatum. J Pediatr Surg 23: 615–622
26. Hecker WC, Happ M, Soder C, et al (1988) Klinik und Problematik der Kiel- und Trichterbrust. Z Kinderchir 43: 15–22
27. Haller JA, Scherer LR, Turner CS, et al (1989) Evolving management of pectus excavatum based on a single institutional experience of 664 patients. Ann Surg 209: 578–583
28. Willital GH, Meier H (1977) Cause of funnel chest recurrences – operative treatment and long-term results. Progr Pediatr Surg 10: 253–256
29. Pircova A, Sekarski-Hunkeler N, Jeanrenaud X, et al (1995) Cardiac perforation after surgical repair of pectus excavatum. J Pediatr Surg 30: 1506–1508
30. McBride WJ, Dicker-R, Abajian JC, et al (1996) Continuous thoracic epidural infusions for postoperative analgesia after pectus deformity repair. J Pediatr Surg 31: 105–107