57 Post-traumatic and Post-surgical Chest Wall Deformities (Acquired Chest Wall Deformities)

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Chest wall deformities may be congenital or acquired secondary to conditions that affect the patient at any stage of life. Although, emphasis has been placed in the diagnosis and treatment of the congenital types of chest wall deformities, acquired chest wall deformities present a completely different aspect depending on the underlying cause that led to the deformity. Acquired chest wall deformities constitute less than 1 % of all thoracic deformities and can be classified in four major groups as presented in Table 57.1 [1].

Introduction

In order to prevent the development of acquired chest wall deformities in young patients resulting from iatrogenic damage which in turn results in impaired chest wall growth after thoracic surgical procedures, it is crucial to have knowledge on the mechanisms of chest wall growth and pathophysiology of the chest wall growth plates.

Approximately, 75 % of the longitudinal growth of a rib takes place at the sternal end and occurs predominantly as a result of endochondral bone formation [3]. Experimental data has demonstrated that chest wall development is severely affected if growth centers of the ribs in the costochondral junction are not preserved during surgical procedures or more than four ribs are resected during a surgical intervention in the thorax; in this case the antero-posterior growth of the chest wall may be affected and significantly retarded [4]. Not only the costochondral, but also the removal of

Table 57.1 Types of acquired chest wall deformities based on the etiological factors

1. Intrinsic pathological processes within the thoracic
Congenital cardiac anomalies with enlargement of the heart *Thymic tumors associated with excessive growth*
2. Pathologies involving the ribs and muscles in the chest wall
Tumors of anterior chest wall ***Infections of the rib(s)***
3. Post-surgical interventions
Operative procedure associated with deformities include *Repair of various types of chest wall deformities* *Harvesting of rib grafts* *Cardiothoracic procedures* [2]
4. Post-traumatic
5. Secondary to alterations in the vertebral column
Scoliosis
Kyphosis

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sub-perichondrial rib cartilages has been reported to result in the formation of a chest wall deformity within 1 year after surgery in up to 50% of the patients [5]. Another important point to be considered here is the damage to the sternal growth center during complete upper transverse ostotomy which is associated with accompanying blood supply disruption, that might play a role in the development of these deformities [6]. Hence, the localization and knowledge of sternal and costochondral growth centers is important, to avoid damage of these centers during surgical procedures in order to decrease the possibility of an iatrogenic related development of a chest wall deformity [1].

Development of Human Sternum and Ribs and Ossification

The embryological development of the sternum is important to understand its formation and to understand the surgical considerations with regards to its embryology. The sternum is of mesodermal origin and is a structure that is formed by fusion of embryonic tissue in the midline of the developing thorax [7]. Cells from two separated bands of mesoderm on either side of the anterior chest wall - *the sternal bars* - migrate toward the midline, and fuse around the 10th week of gestation to form the sternum (Fig. 57.1) [8, 9].

The sites of ossification appear from the cranial to the caudal direction in the manubrium and mesosternum prior to birth, but are not present in the xiphod process until the 6th year of life. The ossification sites are formed in the midline within the intervals between the articular depressions for the costal cartilages in the intercostal spaces. While variations are possible, generally a single site in the manubrium and three major sites in the mesosternum represent most sternal patterns that have been observed at the time of birth [10]. Postnatal sternal ossification is inherent, but three basic patterns have been distinguished and are presented in Table 57.2 (Fig. 57.2) [11]:

Fusion of adjacent mesosternebrae proceeds in a caudal-to-cranial direction, opposite to the initial appearance of the ossification centers. The sternal maturity is characterized by the coalescence of expanding ossification centers, which may be influenced by biological forces to the sternum [12]. The manubrium and mesosternum are completely ossified by the 21st year of life. Ossification of the xiphoid process is usually completed by the 35th year of life but in rare instances may remain cartilaginous throughout life. The ossification centers of the sternum develop from the posterior aspect of the perichondrium first to the lateral part. The anterior domain and the costosternal joints are the last part to ossify [10].

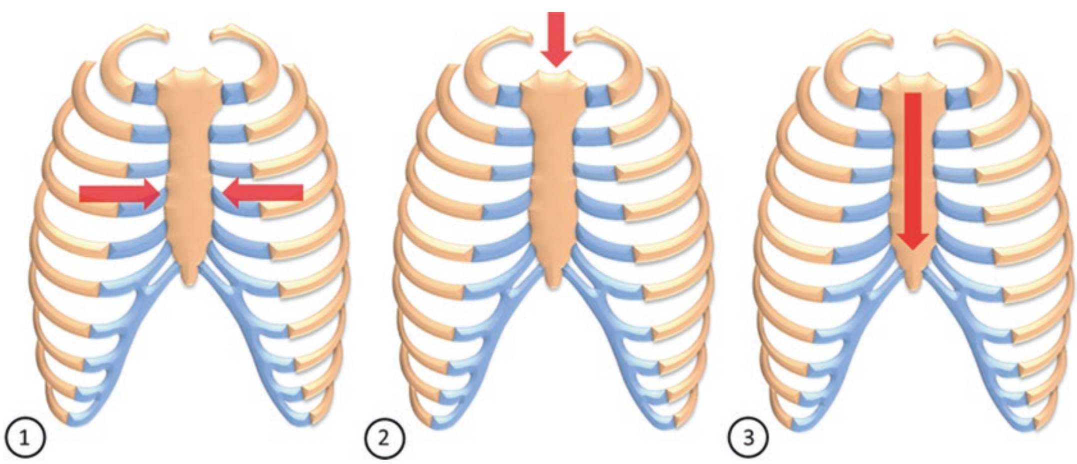


Fig. 57.1 Embryological development of the sternum showing (*1*) the migration of the sternal bars towards the midline. (*2*) The sternal bar fuse towards the cranial part initially to form the jugulum and (*3*) later the caudal progression of fusion leads to the complete formation progressing from the manubrium towards the formation of the xiphoid process

Table 57.2 The three basic patterns of poststernal ossification observed in sternum

Type I	*Ossification is localized in a single midline center in the manubrium and within each of the three mesosternebra which is the square area between the sternal ends of the costal cartilages*
Type II	*Ossification is localized in a single midline center in both the manubrium and first mesosternebra, and also in two bilateral centers of the more caudal mesosternebra*
Type III	*Ossification is localized in a single midline center in the manubrium along with bilateral centers in each of the mesosternebra*

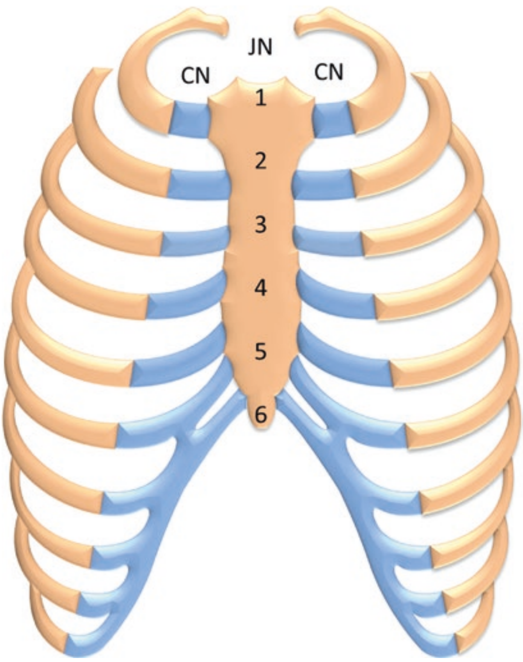


Fig. 57.2 Human sternal anatomy with ossification centers. Clavicles have their insertion in the clavicular notches (*CN*) separated by the jugular notch (*JN*) [9]

Costal cartilage ossification seems to be inhomogenic. The ossification process of the first rib proceeds from the costal toward the sternal end of the cartilage in an anteromedial direction [13]. Approximately 75 % of the longitudinal growth of a rib takes place at the cartilaginous portion of the costochondral junction [3].

There is no satisfactory explanation to understand the etiology of pectus deformities, but there might be evidence from rodent model that damage to the growth plates of the sternum result in predictable patterns of aberrant growth. If sternebrae are seen analogous to epiphyseal centers, surrounded by regions of hyaline cartilage with growth plate potential, then physiological damage might translate in lost potential similar in magnitude and direction to that described for long bones [10].

Iatrogenic Pectus

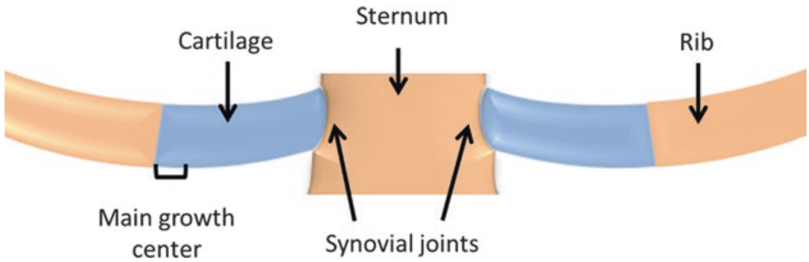
Etiology of Deformities After Pectus Surgery

Deformities of the thorax have been reported in patients that have undergone correction of severe forms of congenital pectus deformities [6, 14]. Due to the clinical findings in these patients who present with a narrow torso, an immobile anterior chest wall and various degrees of dysnpea with decreased vital capacity and forced expiratory volume, this conditioned was termed as “Acquired Restrictive Thoracic Dystrophy” (ARTD) [15]. ARTD was observed in very young children undergoing open pectus excavatum repair with unusual abundant rib resection – that involved removal of three to eight ribs on each side or five to six total rib cartilages bilaterally.

Hence, the normal recommendation for a basic operative procedure would be to resect a 2.5 cm segment of three to four cartilages on each side with preservation of the perichondrium. This observation has further led to the recommendation of delaying open repair in pediatric patients until the 6th–8th year of life [6, 16], with the expectation that the impact on growth failure would be more moderate in older patients if growth plates were to be damaged during a surgical procedure.

It has also been demonstrated that removal of the costal cartilages leads to reduction of the antero-posterior diameter of the thorax, while preservation of 1/4th of the cartilage length at the costochondral junction protects the growth centers of the ribs (Fig. 57.3) [17]. Furthermore damage to the sternal growth center by complete upper transverse osteotomy with corresponding blood supply disruption might cause deformities [6].

Fig. 57.3 Preservation of 1/4th of the cartilage at the costochondral junction has found to protect the growth centers of the ribs



Chest Wall Deformities After Cartilage Graft Harvesting

Costal cartilage harvesting for autologous cartilage tissue transfer is used in many occasions in plastic and rhino-facial surgery, when rigid support for soft tissue reconstruction is needed. These include surgical procedures for reconstruction in microtia which are often performed in young patients [18, 19]. In this procedure to reconstruct the auricular framework, two or more whole costal cartilage grafts are often necessary, with some patients even requiring additional grafts [5]. Donor site complications after such procedure have been rarely reported in the literature; but, increased amount of harvested cartilage is associated with chest wall deformities.

Ohara et al. controlled 18 patients after cartilage harvesting of the ribs for microtia reconstruction. Each cartilage was harvested subperichondrial from the costochondral junction to its free end or attachment to the sternum. The perichondrium, muscle, fascia and subcutaneous tissue were closed in layers. All grafts were taken from the sixth to ninth costal cartilages. It was observed that 16 of 32 ribs from which costal cartilage had been harvested showed increased inward bowing on radiographs. The rate of deformation correlated with age and was more frequent in patients younger than 10 years of age. The deformities were more conspicuous and severe when two or more costal cartilages had been harvested. The rib deformities could usually be observed on radiographs within 1 year of surgery. Interestingly, harvest of the sixth costal cartilage induced over 100 % rib deformities [5].

In 1976, Radford et al. observed in a 6–13 years follow up depression of the chest wall in 16 % of the patients after cartilage harvesting for microtia reconstruction. The technique for harvesting involved the removal of the sixth, seventh and eighth rib cartilages together with the perichondrium, while leaving the synchondrosis between the two larger ribs intact [19].

Thomson et al. also harvested the 6th to 8th rib. Their approach involved the re-adaptation of the intercostals muscle and remaining cartilages with interrupted non-absorbable suture material (Vicryl®, Ethicon Inc, polyglactin 910 sutures), and positioning of the 9th rib cartilage up to the level of the 6th without tension to obliterate the potential margin deformity. The serratus anterior muscle was then approximated with a running suture of 2–0 Vicryl®. Using this approach, a total of 25 % chest wall deformities were observed, with 8 % of them seen in the 6–12 year old children and 33 % in 2–3 year old children [18].

Due to the well-known long term occurrence of chest wall deformity after costal cartilage graft harvesting, a more conservative way of harvesting costal cartilage was developed for rhinoplasty [20]. In this approach, only a central portion of the rib is resected with preservation of intact costal cartilage on three sides (Fig. 57.4).

Due to the better outcomes with this procedure, a brief description of the steps is provided. A 3 cm incision inferior to the infra-mammary crease in the female patients and below the inferior border of the pectoralis major muscle in the male patient is created. The dissection is focused then towards the cartilage of the 7th rib. The rib is then exposed from the lateral osseo-cartilaginous border to the medial junction of the rib and the sternum. A 27-gauge needle is used to evaluate the cartilage and minimize the harvesting of calcified tissue. The perichondrium is incised with a scalpel in the shape of a "T" and periosteal elevator is then used to lift the perichondrium carefully. A 15-blade scalpel is then used to make incisions both at the medial and at

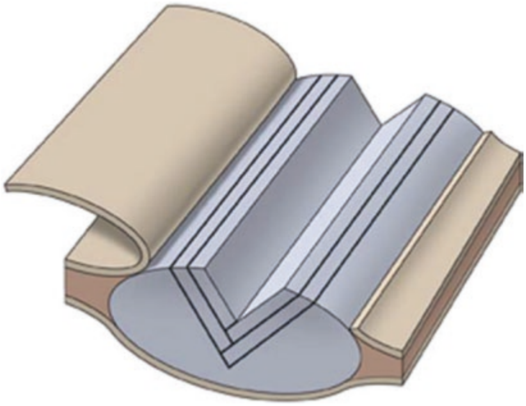


Fig. 57.4 Illustration demonstrating the technique for costal cartilage harvests which decreases donor site morbidity and minimizes warping or displacement (Lee et al. [20]. With permission from John Wiley and Sons)

the lateral aspect of the proposed graft. The incisions should extend through the cartilage but not violate the underlying perichondriuum. At this time an incision is made directly perpendicular to the rib at the mid portion of the rib. The incision is angled at 45° and moves to remove the graft. The initial harvest is usually the largest, shaped like a triangle. Further grafts can be harvested as needed leaving the rib borders (three sides) and underlying perichondrium intact. Only the amount of cartilage that is needed is harvested in order to minimize the amount of tissue that may be discarded later. The overlying perichondrium is now approximated with 4–0 Vicryl suture. The wound is then closed in multiple layers with 3–0 Vicryl used to approximate the muscle. The deep dermis is closed with 4–0 Vicryl, and finally a 4–0 Monocryl is used for the epidermis. Drains are not typically placed in the wound bed after the completion of the procedure. This technique allows for sufficient graft tissue for rhinoplasty, while decreasing donor site morbidity and minimizing warping or displacement.

Iatrogenic Pectus Carinatum After Chest Wall Surgery

Post-surgical pectus carinatum deformities are rare. Swanson et al. reported three patients with "reactive pectus carinatum" after correction of pectus excavatum. Two of these patients were observed to demonstrate this deformity after pectus excatum correction with the Minimal Access Repair of Pectus Excavatum (MARPE) technique while it was observed in one patient after Ravitch procedure [21]. All three patients developed a ventral displacement of the sternum within 1 year after primary intervention. In both patients who underwent MARPE, the bars were removed after 5 months. While in one patient the defect resolved after his pubertal growth spurt, the other patients required two subsequent surgical interventions with costal excision to return the sternum to a neutral position to correct the recurrent pectus carinatum deformity. After the second revision, the sternum was stable in neutral position. In the patient with Ravitch procedure metal removal was done and after 3 years of expectant management, at the age of 17, with computed tomography (CT) scans demonstrating persistent pectus carinatum with bony and fibrous hyperplasia in the anterior chest wall. This patient underwent operative repair involving perichondrial excision and resection of the involved cartilage, and a sternal osteotomy was performed with wedge excision and cartilage graft to deflect the sternum. There was no recurrence of pectus deformity in this patient (Fig. 57.5).

Thompson et al. reported acquired chest wall deformity in 3 month old boy with congenital heart defect that underwent a cardiac surgical procedure [2]. Sternotomy was done twice – once at age of 3 months and repeated at age of 10 months. Approximately, 8 months after the second surgery pectus carinatum was observed. In this case, a revision was performed, and all but one banding wires and excess tissue were removed. During surgery, it was found that the costal cartilage did not appear elongated, but the lower pole of the sternum was prominent. This was shaved down to match the level of the rest of the sternum. Recurrence of pectus carinatum in this patient was not observed.

Post-traumatic Chest Wall Deformities

Reports of post-traumatic pectus excavatum deformities have been rarely reported and documented in the historical literature. In 1931,

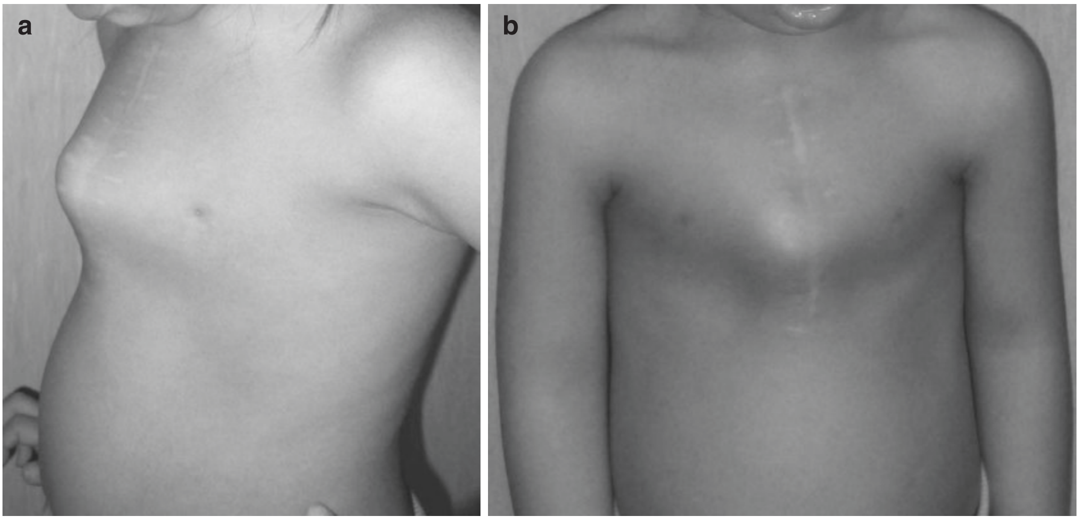


Fig. 57.5 (**a**, **b**) The formation of a pectus carinatum in a 4-year old boy after sternotomy for a cardiac procedure 1 year ago

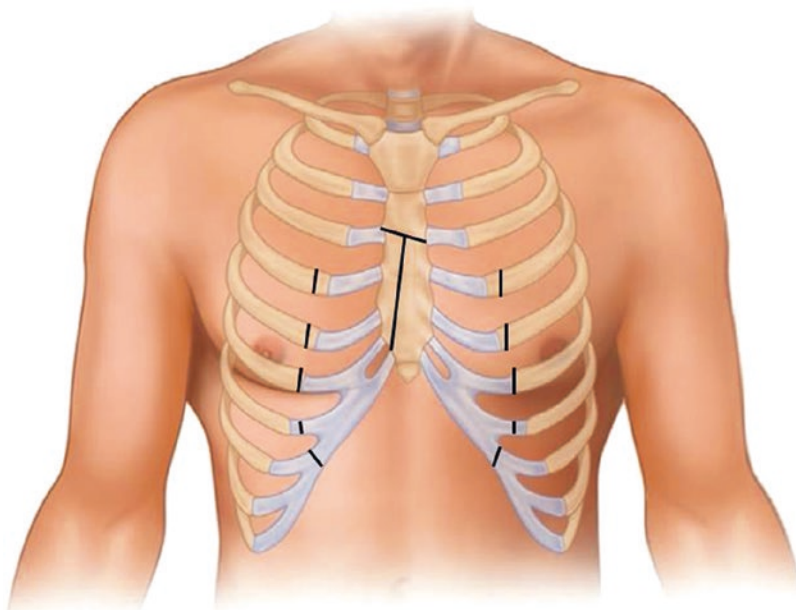


Fig. 57.6 Heavy lines indicating the division of the sternum, ribs and cartilages in order to repair the deformity in the patient [22]

Alexander reported two adolescent patients with post-traumatic pectus excavatum. In one patient who presented at 16 year of age, blunt trauma to the chest wall occurred 4 years ago during a bout of wrestling. The second patient who was a 20 year old woman, was reported to have a blunt chest wall trauma in a car accident 2 years ago. Due to severe pectus excavatum deformity both developed symptoms of dyspnoea and palpitations. The author presumed that multiple fractures of the thoracic cage lead to an inward bending of the frontal thoracic cage due to negative pleural pressure. Both were operated and respiration was improved. In the latter patient excessive sternal callus formation was reported at the time of surgical correction (Figs. 57.6, 57.7 and 57.8) [22].

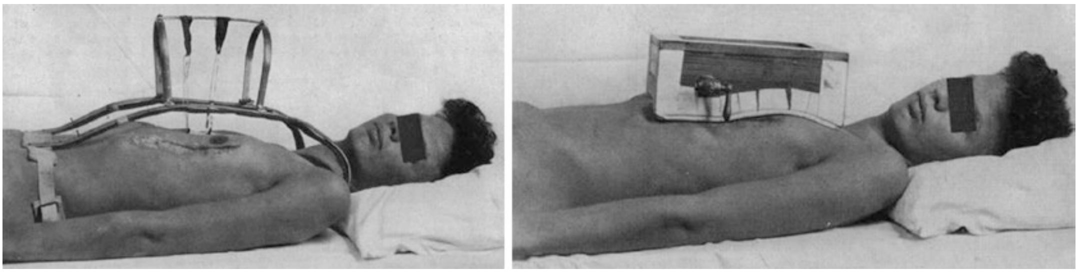


Fig. 57.7 Historical image: device by which reduction of the sternal deformity was maintained for 5 weeks after operation. The band and wire surrounding the sternum are suspended to a bar by rubber bands. *Right*: Box that was air-tight with skin when negative pressure created in it by connecting the pipe with the hospital air suction system. This box was used after removal of the device pictured above in order to maintain reduction of the sternum deformity until firm bony union of the divided sternum and ribs occurred (Alexander [22]. With permission from Wolters Kluwer)

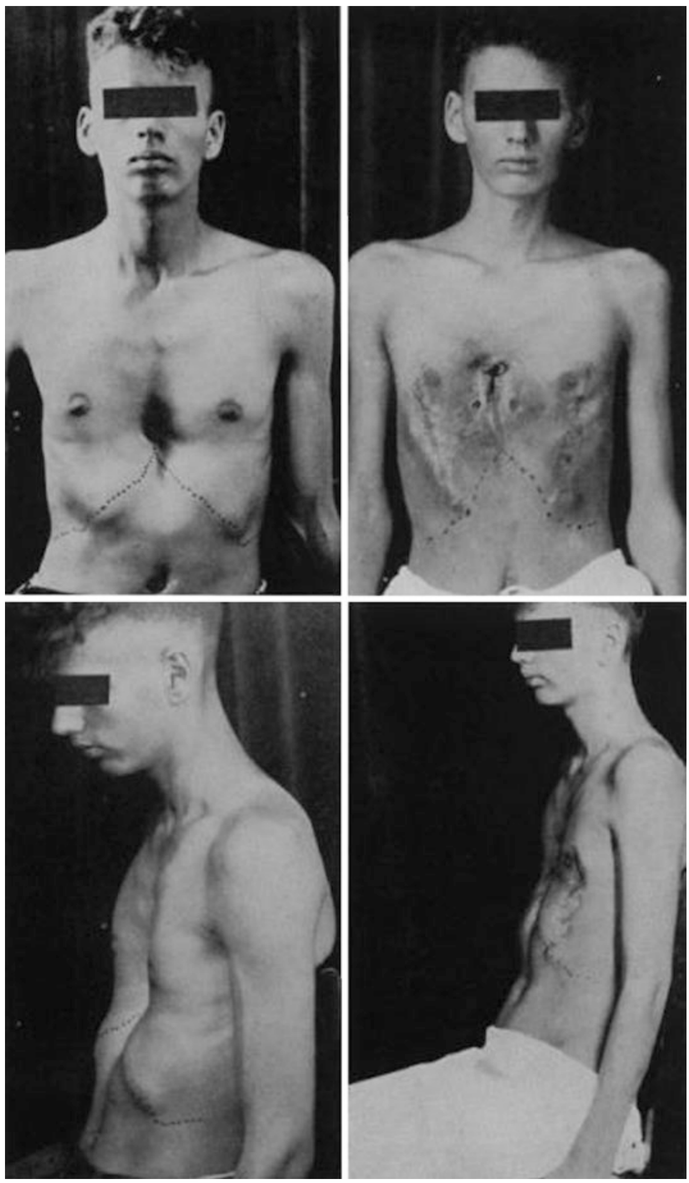


Fig. 57.8 Historical image. The patient who developed a traumatic pectus excavtum- before (*left*) and after (*right*) correction (Alexander [22]. With permission from Wolters Kluwer)

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