Special techniques in the keel chest deformity

7

7.1 The Ravitch procedure

Anton H. Schwabegger

The etiology of the keel chest deformity, still being a hypothetical explanation and a matter of investigation, is probably caused by secondary elongation of rib cartilages during growth spurts, which result in prominences of the rib themselves or are conjoined with a protrusion of the sternum (Figs. 1 and 2a–c) to a variable extent and shape. Therefore, the surgical correction is aimed at shortening the affected cartilages with or without sternum osteotomies.

More rarely such cartilaginous prominences remain isolated from a sternal protrusion, which means that the sternum itself is located in an anatomically orthotopic position, while the adjacent rib cartilages bulge forward symmetrically and appear as parasternal crests extending along a longitudinal axis (Fig. 10 in Chapter 2.3.2). If such cartilaginous crests are present solely unilaterally (Fig. 9 in Chapter 2.3.2), the sternum is usually rotated to the concomitant side, challenging the surgical repair with respect to gain sufficient symmetry.

Fig. 1. Lateral view of X-ray in a male with chondrogladiolar pectus carinatum deformity

7.1.1 Surgical technique

Since the development of the fundamental basics of the surgical technique of pectus carinatum deformity, only minor variants have been described. The basic surgical steps were developed by Robicsek 1963, Welch 1973, Fonkalsrud 2001, and several others [2, 8, 14] and finally resulted in the integrative concept summarized by Ravitch [7], which due to its convincing outcome lasts for decades now [1, 3, 4, 9–12, 14]. Only minor modifications since then are developed, exemplarily noticed the redressing with sternal struts [3] or the muscle split technique [13] to avoid invasive muscle flap elevation (Chapter 7.2).

Usually a midline incision at the sternum enables sufficient survey at the site of remodeling (Fig. 3). Occasionally in unilateral deformities a horizontal incision or in females incisions along the inframammary creases may be opportune (Chapter 5.1).

Prior to the access to the cartilages and sternum in the Ravitch technique however, the Pectoralis major muscles are dissected free and elevated from their sternal and inferior rib insertions to expose the skeletal structures that have to be shaped. The Rectus abdominis muscles may be detached from their origin at the lower ribs, interdigitating with the Pectoralis major muscles. This detachment is performed with inclusion of the xiphoid bone, which means that the xiphoid remains attached thus vascularized via the muscles. The main purpose of such dissection of the xiphoid consists therein that the xiphoid and the muscle origins may more easily be reaffixed to the sternum with strong suture or wires *than* a solely cut muscle without sufficiently strong tissue parts then at the final step of remodeling.

A. H. Schwabegger (ed.), *Congenital Thoracic Wall Deformities*

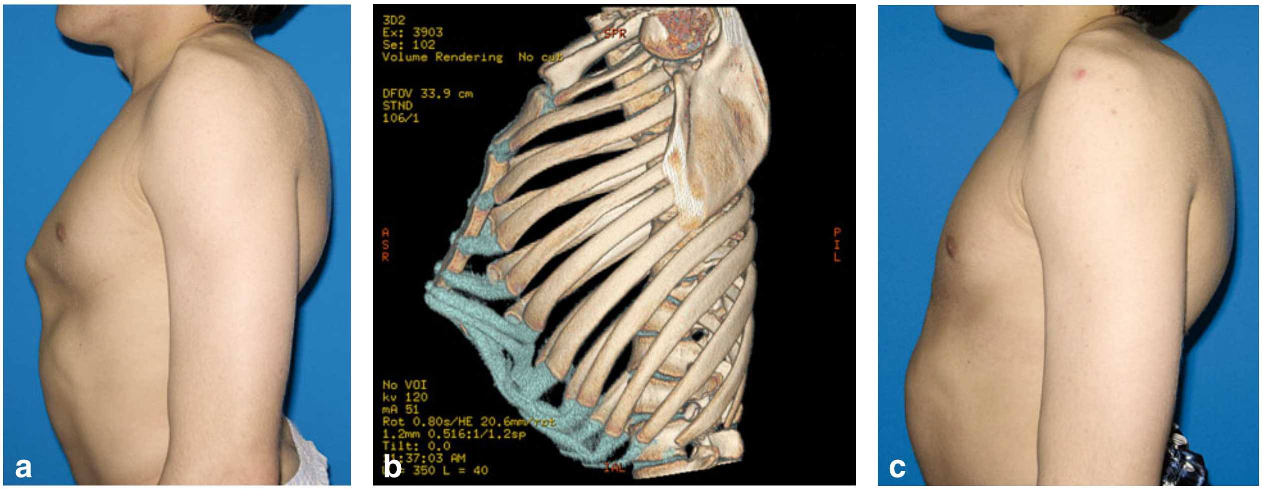

Fig. 2a–c. 20-Year-old male with osteodystrophic microsomia and an extensive chondrogladiolar keel chest preopreatively (**a**) and the corresponding CT-scan depicting the extent of deformity (**b**). Postoperative view with very pleasing aesthetic result

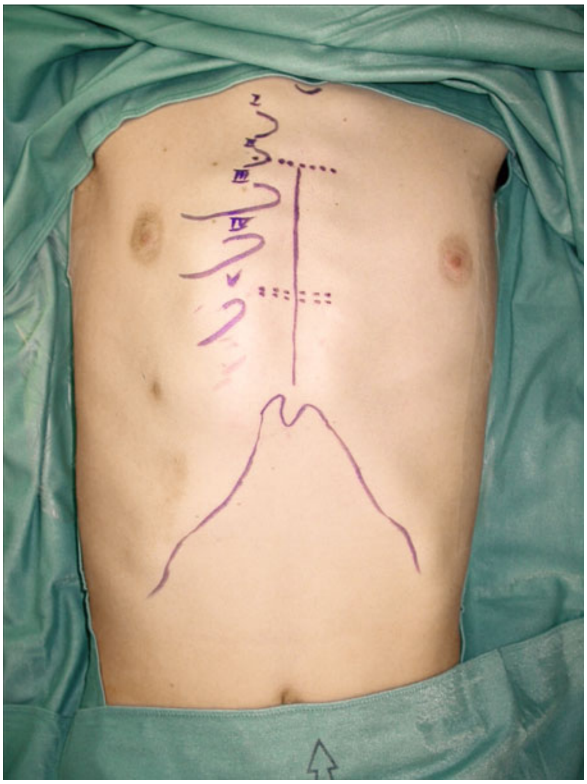

Fig. 3. Intraoperative planning of incision (vertical midline) in 17-year-old male with unilateral keel chest deformity predominantly at the right side. The sites of osteotomies are outlined with short horizontal markings

Fig. 4. Cartilages resected subperichondrally from the 3rd to 6th rib in a case with a bilateral deformity

The first basic step however consists of multiple parasternal rib cartilage resections for the purpose of shortening overabundant length whether they are deformed in a convex or concave manner. Some of these cartilage incisions (chondrectomies) may solely be performed as chondrotomies, when appropriate length of single ribs at individual levels is present. At each individual level with cartilage excess, chondrectomies are done

(Fig. 4), whereas at other levels only a weakening of a distorted cartilage may be advantageous. The extent of cartilage resection in a still growing child should be limited to what is absolutely necessary [3] in order to minimize postoperative development of heavy scarring, which might result in a cumbersome adverse effect, an acquired Jeune syndrome with severe pulmonal restriction based on an anterior thoracic wall growth restriction [5, 6].

The particular characteristic in doing such chondrectomies consists in subperichondrial resections, which means that the cartilages are "peeled" out from the perichondrium tubes, the access managed by door-like incisions at the anterior surface of the ribs. By this, the perichondrium tubes remain in situ for further availability for restabilization. Furthermore, by the subperichondrial access any lesion to the pleura and the intercostal nerves is kept to a minimum.

The second basic component of this concept is single or multiple horizontal sternotomies (Fig. 5) at variable levels, depending on the kind of deformity, whether a chondromanubrial or a chondrogladiolar deformity. Furthermore, even asymmetric cases follow these prin-

Fig. 5. Lateral chest X-ray depicts the situation postoperatively with three horizontal osteotomies performed for remodeling. The lowermost gap represents no osteotomy but a not yet ossificated growth zone, already resulting in a tissue protrusion several months postoperatively

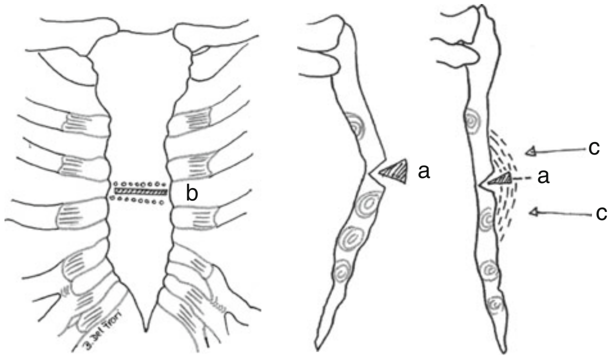

Fig. 6. Schematic depiction of wedge resections (*a*) or horizontal osteotomies (*b*) at the sternum, the level of singular or multiple incisions may differ depending on the shape of deformity and aimed remodeling. A bony wedge may even be used as a transposed autograft (*a*) in order to fill up the defect, which is produced by unbending (*c*) an incised part of the sternum in order to support its final shape

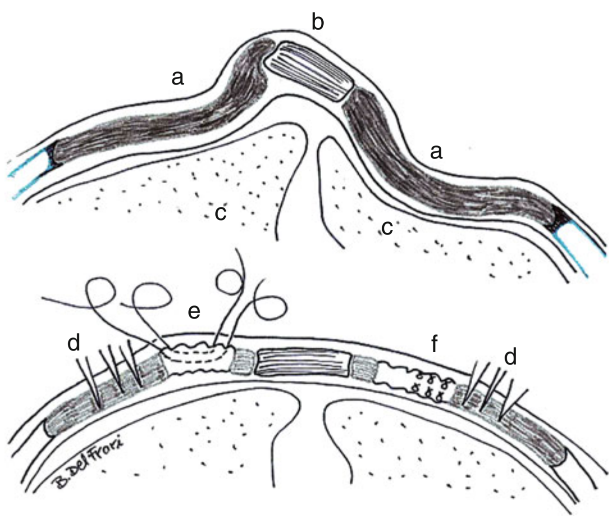

Fig. 7. Deformed cartilages with abundant length (*a*) will be partially resected and for the case of sternum malrotation (*b*) a horizontal osteotomy must be performed. The lungs (*c*) will not suffer from such a remodeling procedure with neglectable alteration onto the intrathoracic volume. The remaining rib cartilages, if still showing protrusion, may be incised at single or multiple sites (*d*) to allow unbending and giving way to the shortening effects on the perichondrium tubes by reefing sutures (*e*, *f*)

ciples. Sternotomy ideally is performed near or at a major protrusion as a wedge resection osteotomy on the one hand, or an incision creating a gap along an ascending slope of the sternal bone in order to enable redressing into a frontal plane (Fig. 6). Usually only the outer table of bone is incised, whereas the inner table will be gently green-stick fractured by forced manual manipulation. If an asymmetric deformity with malrotation of the sternum is apparent, the osteotomy must also include the entire thickness of the sternal bone, in order to alleviate its derotation into a physiologic plane. Incomplete transsection in the symmetrically protruding sternum avoids further dislocation or disruption with the potential sequel of painful sternum pseudarthrosis. If a complete osteotomy for sternum derotation is mandatory, the site of osteotomy therefore must be refixed with appropriate materials.

The third step then is the remodeling process specially featured by perichondrium tube reefing sutures in order to shorten the exceeding surface of the anterior thoracic wall and to restabilize it (Fig. 7).

Thereafter the detached xiphoid with adjacent rectus abdominis muscles will be refixed to the down mobilized and at occasion slightly shortened sternum to put it under tension, thus supporting its flat fixation within a frontal plane [8]. In the case of a present gap produced by osteotomy of the sternum and its redressing to posterior, such a gap may be filled with a bony wedge to allow proper healing there. Every resected part of bone may be used to splint another gap created by the

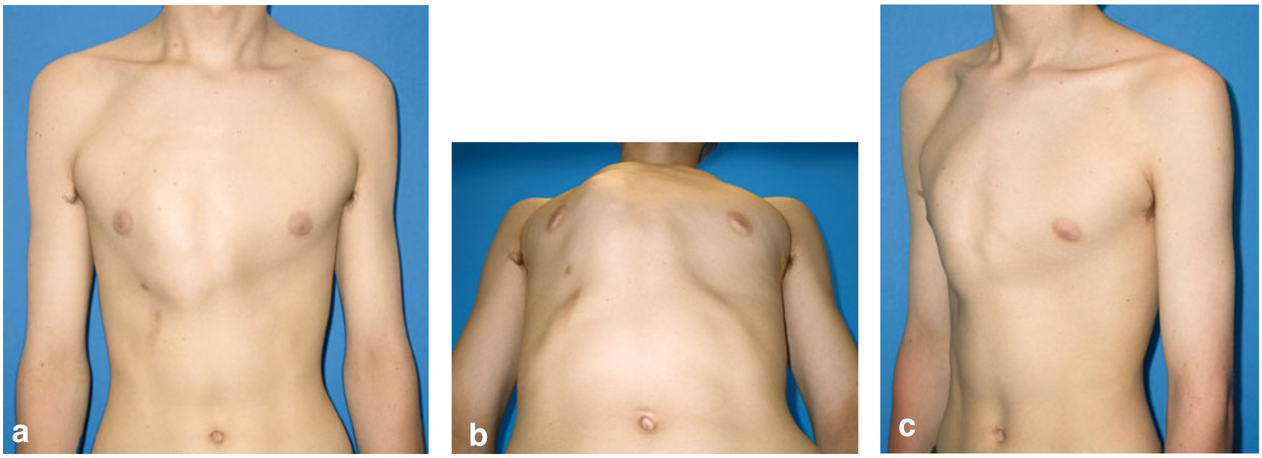

Fig. 8a–c. Same patient as in Fig. 3, preoperatively

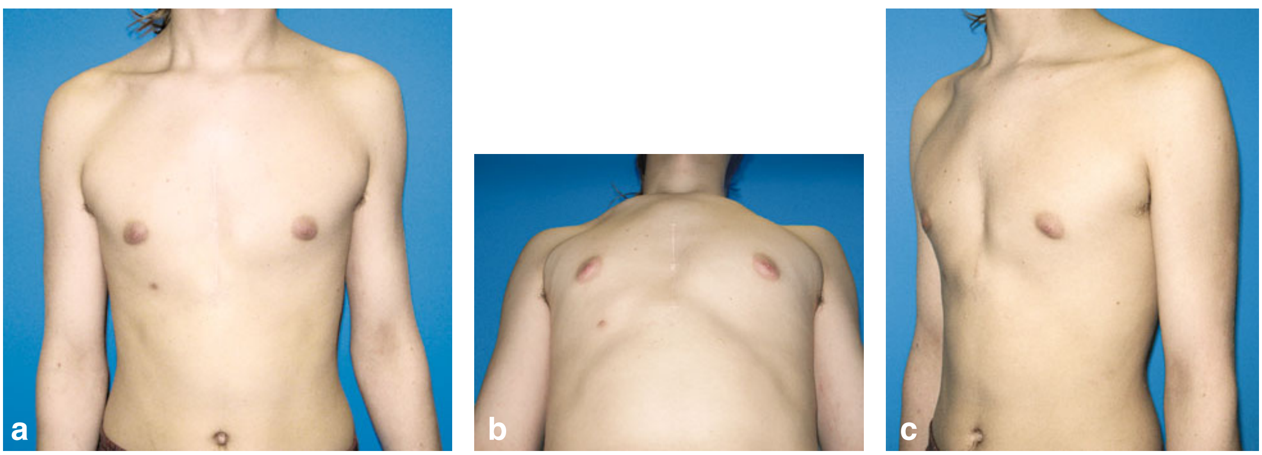

Fig. 9a–c. Same patient 1 year after pectus carinatum repair following the principles of Ravitch, but modified with a 2 months period of postoperative bracing

bone remodeling procedure (Fig. 7). The pectoralis muscle flaps are anatomically repositioned to the sternum and the ribs to regain and maintain their original function.

In general, these steps of the basic concept after Ravitch may be applied to the majority of all variants of keel chest deformities (Figs. 8 and 9), since the key points of shaping all kinds of protrusions consist of redressement of mobilized bone and rigid shortening of lengthy ribs. Usually the aesthetic outcome of this kind of surgery even applying several modifications results in good to excellent appearance in up to 97% of all patients treated for pectus carinatum deformities [3].

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7.2 Modifications of the Ravitch technique for correction of pectus carinatum with split muscle, bioabsorbable osteosynthetic material, and brace: the Innsbruck concept

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7.2.1 Introduction

In this chapter, the experience with a modified access for the correction of the pectus carinatum deformity is described. The modifications versus the classic Ravitch [19] procedure exist in multiple minor splitting of the pectoralis major and rectus abdominis muscles [25], the use of bioabsorbable osteosynthetic material and the application of a compression brace postoperatively [24]. Especially this combined treatment access has proved itself very advantageous, on the one hand to reduce pains and on the other hand to improve the late result in regard to shaping and minimizing scar markedness.

7.2.2 Methods

First, especially the use of the muscle split technique permits mobilization of the shoulder belt relatively early after surgery, because in this access the pectoralis major and the rectus abdominis muscles are solely split along their fiber direction and in contrast to the conventional Ravitch technique need not to be elevated as partial muscle flaps from the ribs and the sternum.
Second, as an additional modification, and opposite to earlier described methods we nowadays use bioabsorbable plates and screws (Bionx, Tampere, Finland) [2, 5, 12] for refixation of the osteotomized sternum, which disintegrate after one to 2 years completely.
Third, to improve the long-term result of remodeling and stable healing of the sternum osteotomy and close-by chondrotomies as well as to reduce the risk of hypertrophic scar formation, a special custom-made keel chest brace (Chapter 7.4) is applied for 2 months [24, 25].

7.2.2.1 The muscle split technique

The conventional access to the correction of the pectus carinatum was described in many series and sufficiently long-term observations over the past decades. Above all the authors Ravitch, Robicsek, Fonkalsrud, and several others have contributed very much to the previous development and refinement of surgical development [4, 6–8, 19–22, 26]. The refinements of these authors predominantly range on modifications of the osteochondrotomies and fewer on the treatment of the soft tissue. However, precisely because rehabilitation time [23] is substantially linked with function of the pectoralis major and rectus abdominis muscles, we considered how the postoperative mobilization and healing phase could be reduced with regard to impairment of the surgical damage to the muscles. In the conventional technique, the sternal and partially the costal part of the pectoralis major as well as the cranial part of the rectus abdominis muscles are detached from their periostal insertions to the sternum, xiphoid and ribs and then elevated to expose the relevant rib cartilages (Fig. 1). This procedure up to date appeared to be necessary to alleviate a clear access to the site of osteochondro-

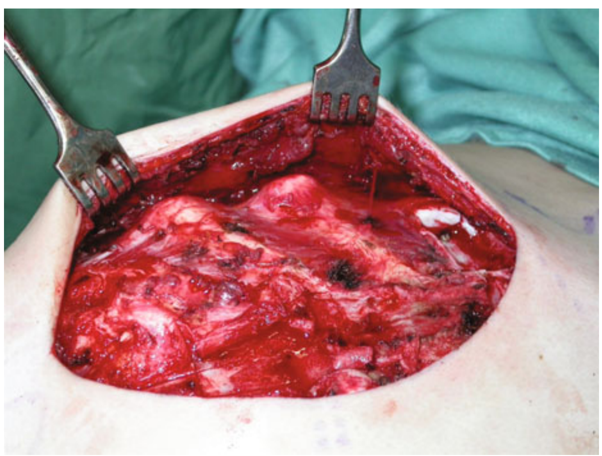

Fig. 1. Skin and muscle flaps elevated to provide with access to the deformed rib cartilages, the intercostal parasternal perforator vessels are transected

tomies. This rather invasive procedure with raising of muscle flaps on the one hand is of major advantage because of the outcropping survey to the anatomical structures to be dissected and on the other hand it also permits a very exact judgment of the surgical steps of remodeling the anterior thoracic wall.

Apart from that issue these muscles are developed very vigorously particularly in young athletic male patients and must be refixed anatomically with outstanding accuracy, what is to be managed at the sternum and periosteum sometimes very badly. The edges of the sternal part of the pectoralis major muscle may be easily sutured together in the median line, but this action will create an unnaturally looking aesthetic appearance of the décolleté. Furthermore, it is of disadvantage that this anatomically reattached muscles, based on the powerful lever effect of the shoulder belt, must be put to rest and be partially immobilized for up to 6 weeks. With regard to postoperative rehabilitation such a period of physical exercise restriction clearly affects the quality of life temporarily and should be subject of avoidance [25].

It therefore appeared meaningful to elaborate a method, with which the muscles did not need to be elevated and thus temporarily suspended from function. A transmuscular access then seemed to be the natural alternative, for each rib individually and with only minor damage to the muscles coevally. In 1970 Jensen [11] described such an access with several transmuscular incisions to reach the individual ribs for transection, however in the pectus excavatum deformity. Likewise these transmuscular accesses in the correction of pectus carinatum are aligned (Figs. 2–6) along the muscle fiber direction and therefore do not substantially damage the muscle and further on only temporarily and slightly impair the entire function. The sternum osteotomy in most

Fig. 2. Marked blue line at the Pectoralis major muscle showing the incision line along the muscle fibers for the transmuscular access to the ribs

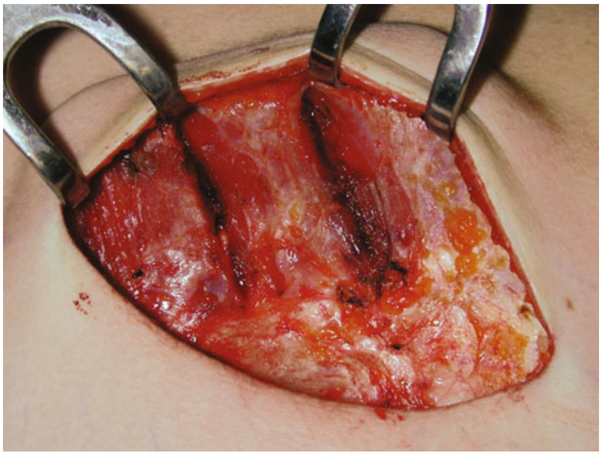

Fig. 3. Individual incisions through the muscle fascia and ensuing blunt separation of muscle fibers depict the ribs underneath with only minor damage to the muscle itself

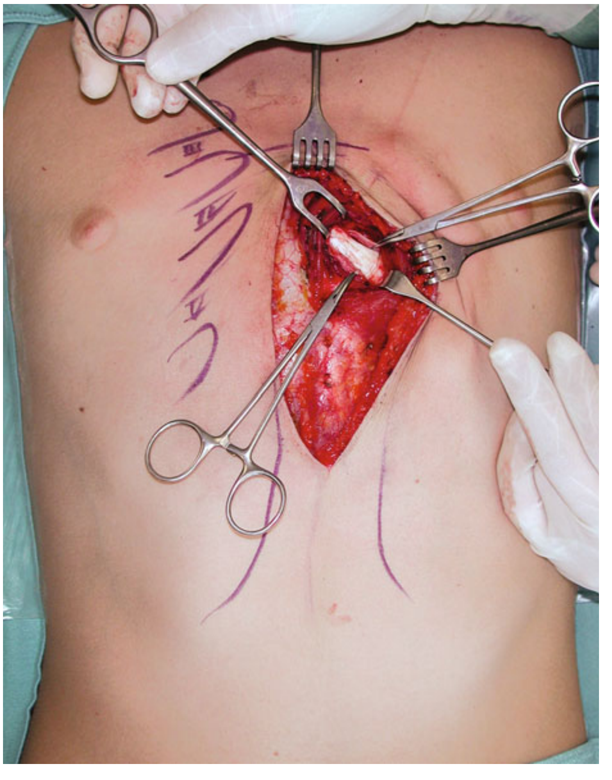

Fig. 4. The muscle margins are retracted and the individual ribs exposed for sub-perichondral resection

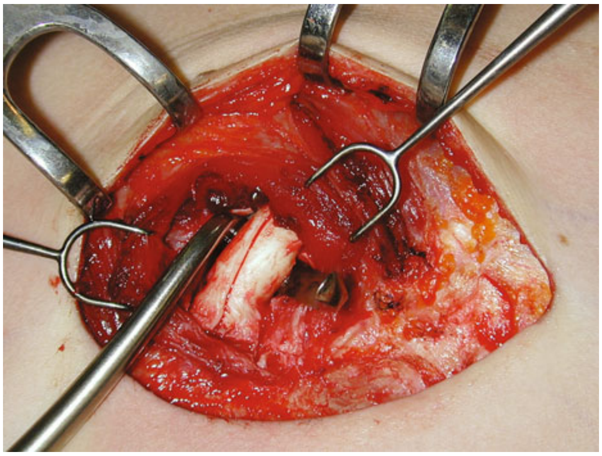

Fig. 5. A specially shaped rib dissector is used to elevate the rib cartilage and enables its careful transmuscular resection

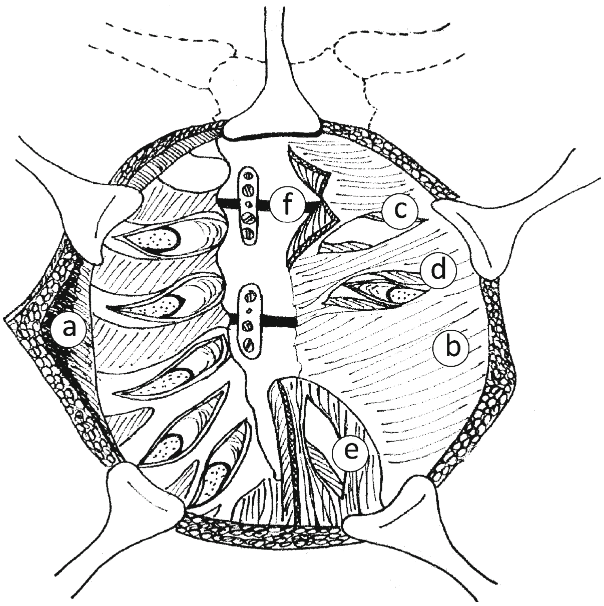

Fig. 6. Schematic overview of conventional technique at the patient's right side and muscle split technique at the left side. *a* Retracted pectoralis major muscle and skin flap with rib cartilages resected. *b* Pectoralis major muscle left in place with several transmuscular splittings (*c* and *d*), *e* muscle split along the rectus abdominis muscle to expose the seventh and eighth rib cartilages, *f* slightly elevated periosteum and horizontal sternum osteotomy with absorbable osteosynthetic material

cases necessarily along a horizontal line usually can be carried out (Fig. 7) easily by a separate access with a door-like incision (Fig. 8) of the periosteum without essential relief of the adjacent pectoralis major muscles. After osteosynthesis with bioabsorbable plates and screws (Figs. 9 and 10) the elevated periosteum

Fig. 7. Planning of surgery with skin markings showing the site of vertical median skin incision and horizontal sternum ostetomy

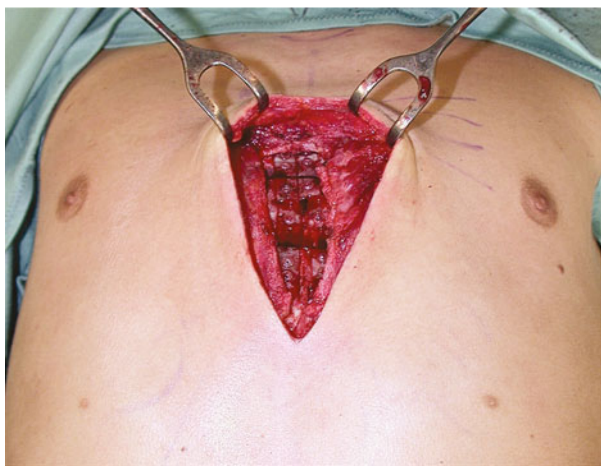

Fig. 8. Wing-door shaped incision of the sternum periosteum, the absorbable plates and screws bridging and fixing two horizontal osteotomies. Note the muscle margins are still inserting to the lateral sternum borders

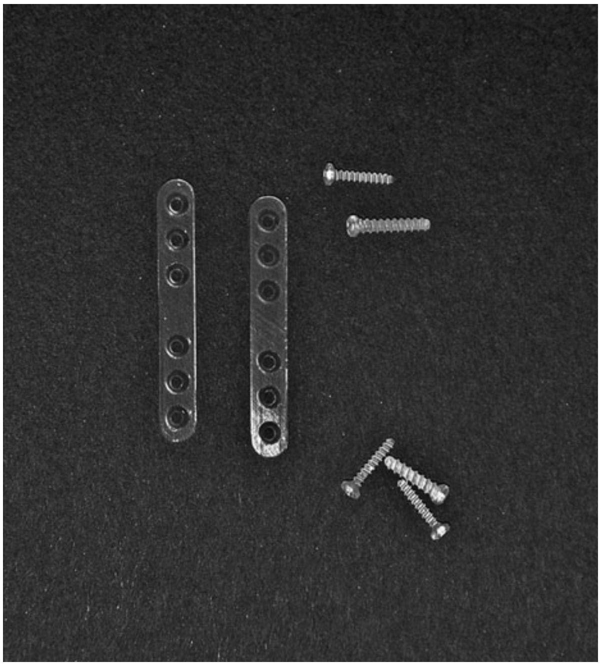

Fig. 9. Absorbable osteosynthetic material used for sternum refixation

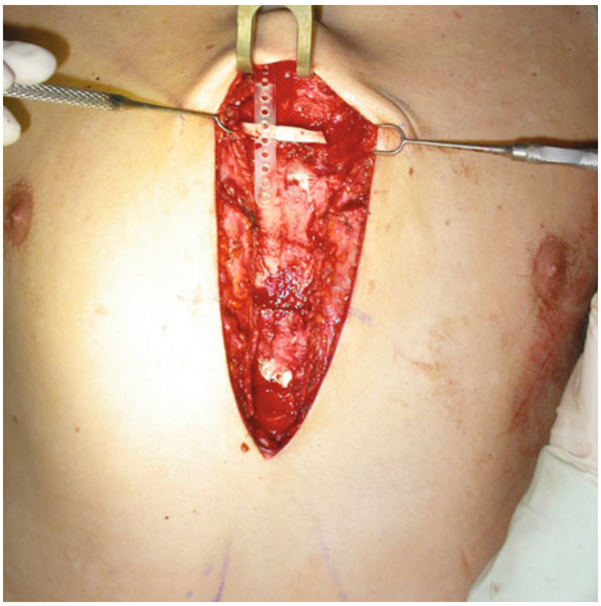

Fig. 10. The wedge-shaped horizontal bone incision is filled with a cortical bone part excised from the lower anterior compacta of the sternum, fixed, and kept in place by the absorbable plate

will be reattached above the embedded osteosynthetic parts with strong sutures. In minor, unilateral or also in more extensive keel chest deformities this

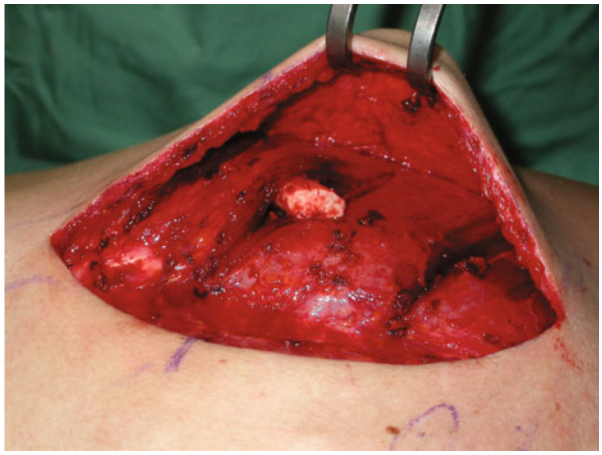

Fig. 11. Transmuscular dissection of rib cartilage in an athletic male with considerable pectoralis major muscle bulk

muscle split technique has proved itself exceptionally helpful [25]. The operation times do not substantially exceed those of the conventional technique, however, due to the retromuscular depth of the location of ribs (Fig. 11), the overview for the sub-perichondral resection of rib cartilages is somewhat restricted. In doing so, the risk of pleura lesion is probable. Based on that narrowed survey, above all in very athletic patients with thick muscle bulk, this access appears somewhat complicated. On the other hand, right in athletic persons with the urge to the muscle exercises and sports activities, a long period of movement and strain restriction will result in inadvertent atrophy of well-defined muscles.

7.2.2.2 Surgical technique

The skin incision design does not differ from the classic Ravitch procedure, usually a cranial to caudal vertical cut along the median line is performed (Fig. 7). In female patients, the incisions are set preferably along the submammary crease (Fig. 12) not to compromise the décolleté in its appearance (Chapter 9). Also in solely unilateral deformities, in which under circumstances no sternum osteotomy is necessary, the skin incision may be orientated horizontally (Fig. 13, Chapter 5.1). Subsequently the skin and subkutis flaps are elevated along the pectoralis major and rectus abdominis muscles (Fig. 2). The ribs of interest are palpated through the muscles and the muscle fibers are bluntly separated to reach the perichondrium of the ribs (Fig. 3). These transmuscular accesses measure 3–6 cm each depending upon the length required for rib cartilage transection or resection. Herewith an individual transmuscular access is created

Fig. 12. Surgical access is a female with asymmetric and predominantly unilateral pectus carinatum deformity, using a submammary incision only

Fig. 13. Horizontal skin incision in a male with unilateral deformity. All deformed ribs cranial and caudal from such a skin incision may be reached for excision or transection

for every rib cartilage (Fig. 5). In areas where the rib cartilages course more oblique to caudal, one muscle separation slit allows access to even two adjoining rib cartilages. This is rather probable at the level of the fifth, sixth, and seventh rib, where the rib cartilages are joined and a correspondingly widened access must be selected. Above all, it is of importance to split muscles along the direction of fibers as well as the insertion fascias preferably in a rectangular direction to the ribs in such a way that almost all of the muscle insertions remain in situ. Because at the lower ribs, where cartilage parts are transected and/or resected, several muscle slips from the oblique abdominal muscles insert. Therefore it is of paramount importance to put accurate reefing sutures (Chapter 7.1) to the perichondrium sleeves to guarantee stable muscle function. Furthermore all of the anterior fascia sheet of the rectus abdominis muscle must be repositioned and secured tightly with sturdy sutures in order to avoid abdominal wall bulging, which however is more common in the conventional procedure with total muscle release from the lower ribs and xiphoid [14, 23].

The length of the muscle separation should not exceed 6 cm in order not to impair the muscle innervation, as the concerning nerves course from lateral to medial. Emerging from the brachial plexus as medial and lateral pectoral branches they initially, at the lateral third of the muscle portion and underneath of it, run in a vertical fashion. Subsequently they divide further up in tiny branches, align to the muscle fibers, and enter them [3, 15, 18, 28]. The more medial blunt muscle separation for access to the cartilages is performed, the lesser is the probability of innervation damage (Fig. 14).

A special additional advantage using this muscle split technique without elevation of muscle flaps consists therein that the parasternal perforator vessels emerging from the Internal thoracic vessels remain pre-

Fig. 14. Schematic depiction of the medial and lateral pectoral motor nerve branches emerging from the brachial plexus. Note the course, first descending vertically and then more medially running parallel to the muscle fibers, where blunt muscle splitting is performed to expose the rib cartilages

served totally. This fact of entirely untouched and preserved muscle vascularization at the parasternal region enables an optimal wound healing at the area of thoracic wall remodeling. It will obviously and substantially allow a quicker healing in contrast to the procedures, in which the muscles are elevated as flaps and many perforator vessels have to be transected inevitably.
For the case that in females a horizontal sternum osteotomy has to be carried out, this usually succeeds also from the incision along the submammary crease. Herein the utilization of an angled retractor with attached light source (Fig. 15) enables sufficient overview underneath the elevated skin flaps. Furthermore, an oscillating saw with an angulated blade has proved itself as very advantageous to reach the distantly and subcutaneously localized bone transection line (Chapter 5.1, Fig. 16).

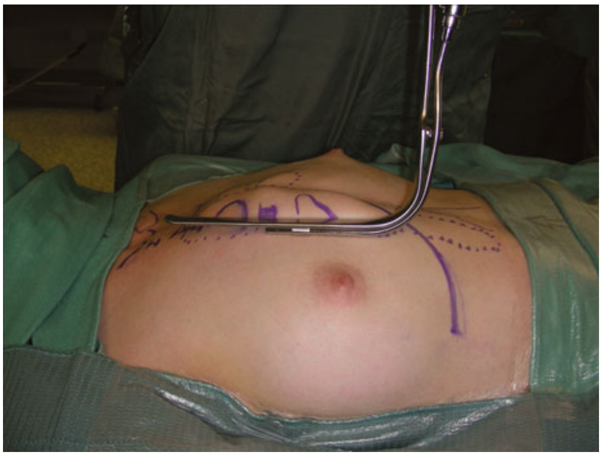

Fig. 15. An angled retractor equipped with a light source to allow appropriate overview for surgical maneuvers beneath the elevated skin flap

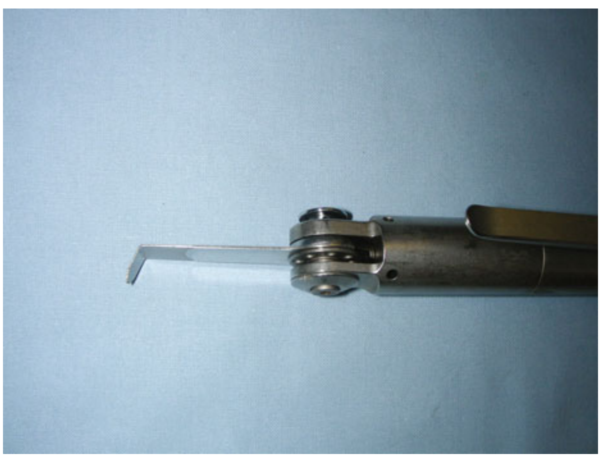

Fig. 16. An oscillating saw with an angled blade to enable sternum osteotomy from a distantly set skin incision

7.2.3 Discussion

The until now established technique of Ravitch (Chapter 7.1) includes determined standards, independent of the size or the localization of the keel chest deformity. The pectoralis major and rectus abdominis muscles are elevated as muscle flaps from the sternum and the parasternal rib cartilages. They are reflected to lateral as well as to caudal to expose disfigured rib parts. Such a creation of extended wound areas in the submuscular area with extensive desinsertion of musculature does not appear absolutely necessary for the intervention at the skeletal structures. Therefore, a modified access utilizing limited transmuscular approaches on every individual levels of the disfigured single rib seemed to be a practicable alternative. Through solely blunt separation of muscle fibers, it hardly comes to hemorrhage and therewith blood loss is negligible. It furthermore appears as a special benefit that such blunt muscle preparation and the avoidance of muscle flap elevation lead to substantially lesser consumption of postoperatively required analgesics [25]. On the one hand, this is because the invasive wound surfaces remain far smaller and almost all of the muscle fibers remain inserted. A peridural catheter which is usually proposed in the standard techniques can therefore be left off except for cases with very extensive deformities. As a further consequence of such diminished pain phases probability of earliest discharge from the inpatient treatment ensues.
The particular advantages in performing the muscle split technique consist of:
- substantially reduced wound area,
- less hemorrhage,
- remaining muscle and fascia insertions,
- almost no risk of muscle retraction,
- immediate postoperative mobilization, and
- unimpaired postoperative range of shoulder motion.

Minor disadvantages consist of:
- lesser overview to rib cartilages and
- more risk for minimal pleura lesion.

If a sternumosteotomy is not necessary and only parasternal chondrotomies are applied, however using

the muscle split technique, full mobilization of the shoulder belt already after few days without strain is permitted. These exercises can be upgraded then after the third postoperative week, which is in explicit contrast to the conventional technique, where several more weeks more of rest to relieve the muscle sutures is advised, particularly in adolescents and adults. For the case that sternum osteotomy is carried out simultaneously within the remodeling procedure, the full exercise strain is permitted first after the sixth postoperative week whereby however from the third postoperative week already, based on the remaining muscle insertions, full passive mobility is permitted.
The use of absorbable osteosynthetic material (Figs. 9 and 10) additively supports bone healing, whereby this means no essential advantage versus the utilization of wire cerclages. Nevertheless wire cerclages are permanently remaining foreign objects and can cause local problems such as skin irritation or perforation by loosening after months or years. Occasionally these wire cerclages are permanently palbable or even well visible in slim patients. On the contrary, absorbable osteosynthetic material is resorbed by autolysis (Fig. 17) within 1–2 years completely [2, 16, 17, 24, 25]. Additionally, these devices can be cut with scissors or hot electric loops and tailored according to the size required. Manipulation or bending at room temperature is possible without affecting their performance. Thus, they can be formed exactly enabling reliable and secure bone and cartilage fixation to allow precise sternal reposition. These plates and screws give the surgeons unlimited possibilities to reshape and to adapt the bone-cartilage complex to the defect with minimal manipulation and injury of blood supply.

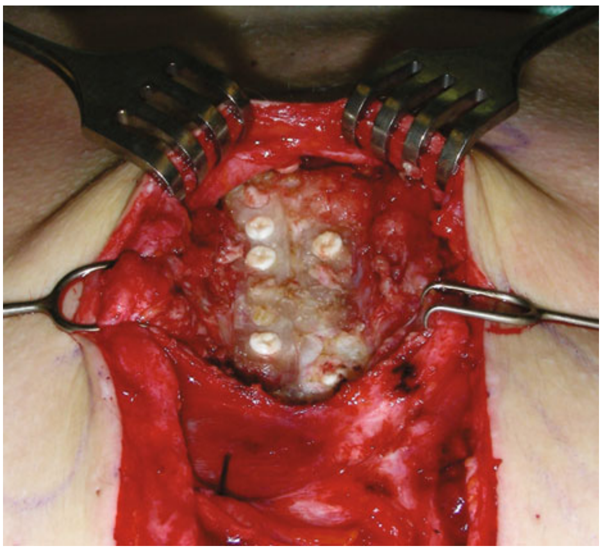

Fig. 17. Absorbable osteosynthetic material during the process of disintegration in a case with minor corrective surgery of remnant rib humps 1 year after remodeling surgery

Fonkalsrud in 2004 [7] described a modification of the Ravitch technique using temporarily implanted metal struts for 6 months. The argumentation was that such a metal strut produces stability to the anterior chest wall during the healing phase and therewith prevents the danger of recidive development with sternum protrusion. Abramson recently described a modification of the Nuss procedure but in contrast to that using the pectus bar as a compressive device, placed subcutaneously or beneath the pectoralis muscles. The results seem to be promising so far, avoiding extensive surgery and median scars [2]. However an essential disadvantage is that this strut must be removed after 6–12 months and therewith further surgery and hospitalization is necessary. Absorbable plates and screws for sternum refixation and a postoperative keel chest brace circumvent this necessity of a rigid internal fixation and a second intervention. Already Matsui and Gürkök applied large bioabsorbable copolymer plates and screws for the correction of pectus excavatum deformities, but not in the carinatum deformity [9, 16]. However, such voluminous and thick absorbable plates are not desired because they are very well palpable and visible through the presternal skin and furthermore yet require a substantially long absorption time. The use of small platelets and screws (Fig. 9) in connection with postoperative bracing permits a similarly rigid immobilization of the anterior thoracic wall for the period of bone healing and scarring of the reefed perichondrium sleeves. The use of such absorbable osteosynthetic material (Bionx™, Tampere, Finland) for pectus carinatum surgery until now caused no complications at all [24, 25].
Moreover, an additional protection through immobilization of the osteotomized and refixed sternums is produced using the keel chest brace postoperatively (Chapter 7.4), what yet moreover eases the postoperative mobilization maneuvers. Bearing the keel chest brace permanently for 23 h daily contains a further advantage, namely the permanent compression of the scar over a period of 2 months. This causes, also well known from the literature [29], a reduction in the probability of development of inadvertent scar formation (Chapter 12.2). The distinct compression effect of the brace paddle to the scar is

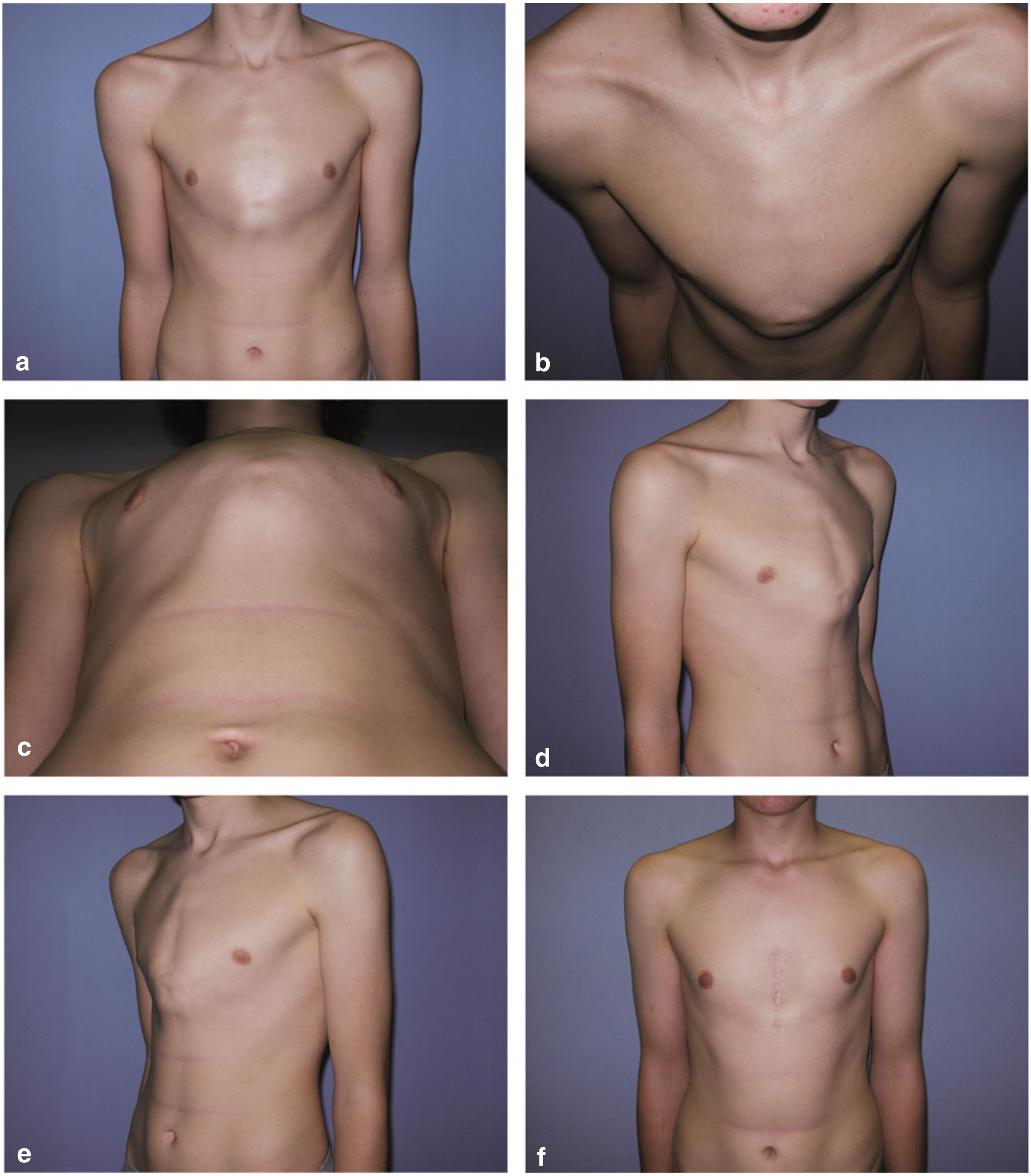

Fig. 18a–e. Preoperative situation in a 16-year-old male with symmetric chondromanubrial deformity. **f–j** Situation 1 year postoperatively after modified repair with muscle split technique and 2 months of keel chest bracing.

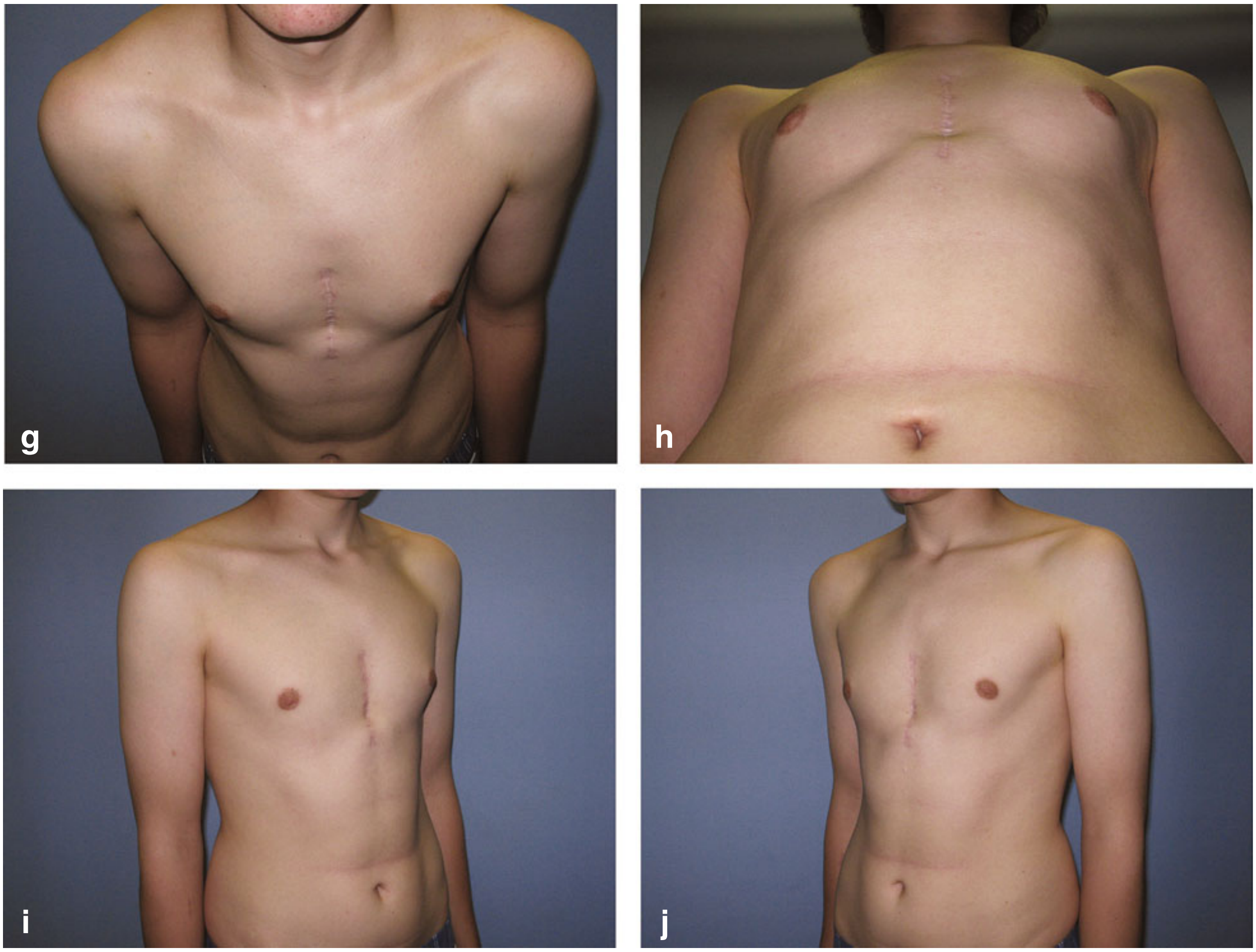

Fig. 18. (*Continued*)

evidently visible in Fig. 7 of Chapter 5.1 as well as in Fig. 4 of Chapter 7.4. A silicone containing surface mounted on the compression paddle additively successfully avoids hypertrophic scar development (Figs. 18 and 19).

Nevertheless a slight disadvantage must be noted such as the transmuscular access yields a somewhat limited view to the rib cartilages and perichondrium. Particular caution must be deployed because of the relatively narrow transmuscular access, especially in individuals with well-trained bulky muscles to avoid injuries of pleura and lung. If the deformity is extending very laterally, the muscle separation must be carried out very carefully and ideally with the aid of magnifying loupes to protect the pectoral nerves hereby passing partially oblique to the muscle fiber direction. Even partial or minor nerve branches severing causes partial muscle atrophy and diminishes function and aesthetic appearance.

For that reason and in marked deformities, the conventional approach with muscle flap elevation for remodeling still is suggested to circumvent nerve lesions. Anyhow the muscle split technique can be applied in the caudal thoracic area at the rectus abdominis muscle also (Fig. 20).

Comprehensively we recommend the use of the muscle split technique in patients suffering with lesser or moderate Pectus carinatum deformity, if not more than five rib cartilages must be incised or shortened. In cases requiring access to more than five ribs on each side the conventional Ravitch procedure is still the first choice of approach. However, no evidence-based studies comparing the Ravitch procedure with the modified muscle split technique exist to date. A

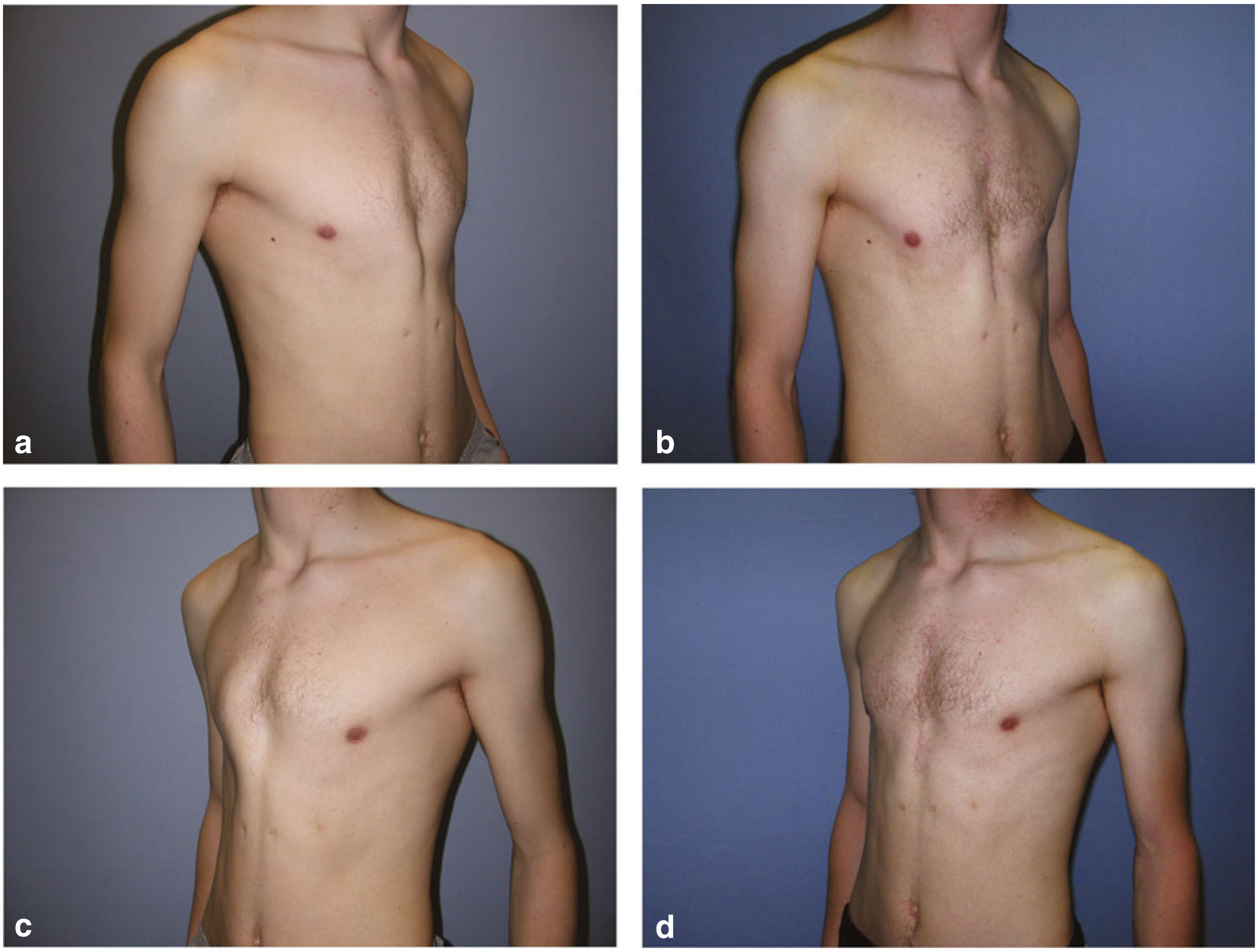

Fig. 19a, b. Preoperative situation in a 19-year-old male with moderately asymmetric chondromanubrial deformity. **c, d** Situation 1 year postoperatively after modified repair with muscle split technique and 2 months of keel chest bracing

prospective study design seems no longer be possible because based on previous and ongoing experiences it now is considered essentially to avoid pains and long-term periods of immobilization. Therefore the conventional technique in the mild and moderate deformities has been abandoned at our institution for the benefit of the patient.

Solely compressive orthotics [10, 13, 27] without surgery may diminish the extent of minor deformities if applied early in childhood and if applied for many months, depending on a long-lasting endurance of the affected patients. However, to our experience only the combined treatment of surgery with postoperative compression provides with the best aesthetic outcome so far but resulting in a surgically produced scar.

7.2.4 Conclusion

Our previous experiences showed that the modification of the conventional Ravitch technique, according to the Innsbruck concept with muscle split technique, use of absorbable osteosynthetic material as well as the postoperative keel chest brace, reduce the entire morbidity of the intervention itself. Thus the postoperative rehabilitation phase for the patients is substantially shorter and remains more comfortable. Consistently good to perfect aesthetic results after keel chest surgery however may differ in using these different techniques, namely both the conventional Ravitch procedure or the modified Innsbruck approach. This may not be ascribed to the muscle split technique alone but rather to the integrated treatment with utilization

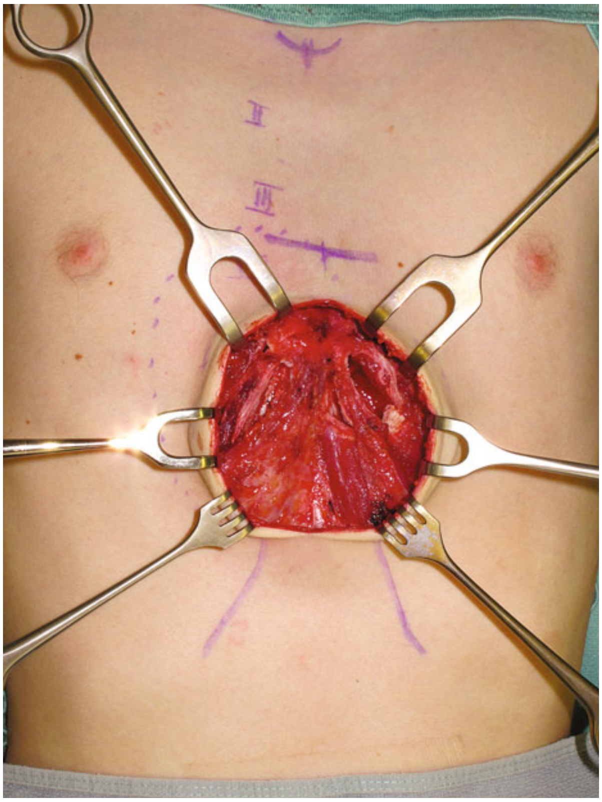

Fig. 20. Longitudinal muscle splitting at the rectus abdominis muscle in order to expose and enable partial excision or transection of the lowermost rib cartilages

of a keel chest brace, which on the one hand permits a more stable support for healing of the severed skeletal structures and on the other hand minimizes the risk for the development of hypertrophic scars or even keloids.

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7.3 Cartilage chips for refinement after keel chest remodeling

Anton H. Schwabegger

This chapter, in analogy to Chapter 6.6.1, describes the appropriate use of cartilage chips in the corrective refinement of remaining depressed deformities after or during the surgery of asymmetric or mixed (pectus arcuatum) expressions of keel chest deformities. The detailed technique is described in the referred chapter and substantially does not differ in harvesting, comminution, and wrapping into surgicel® as well as reimplantation into subcutaneous pockets.

Usually plenty of excised rib cartilages is availabe after the standard Ravitch procedure in the keel chest surgery, commonly subject of biological disposal. Instead of wasting these abundant cartilages, they all or in parts may be utilized, whenever appropriate, to fill up concomitant contour defects to some extent.

Such refinements by utilization of autologous cartilage grafts can be required, when irregularities in the contour of skin surface of the anterior thoracic wall e.g. develop

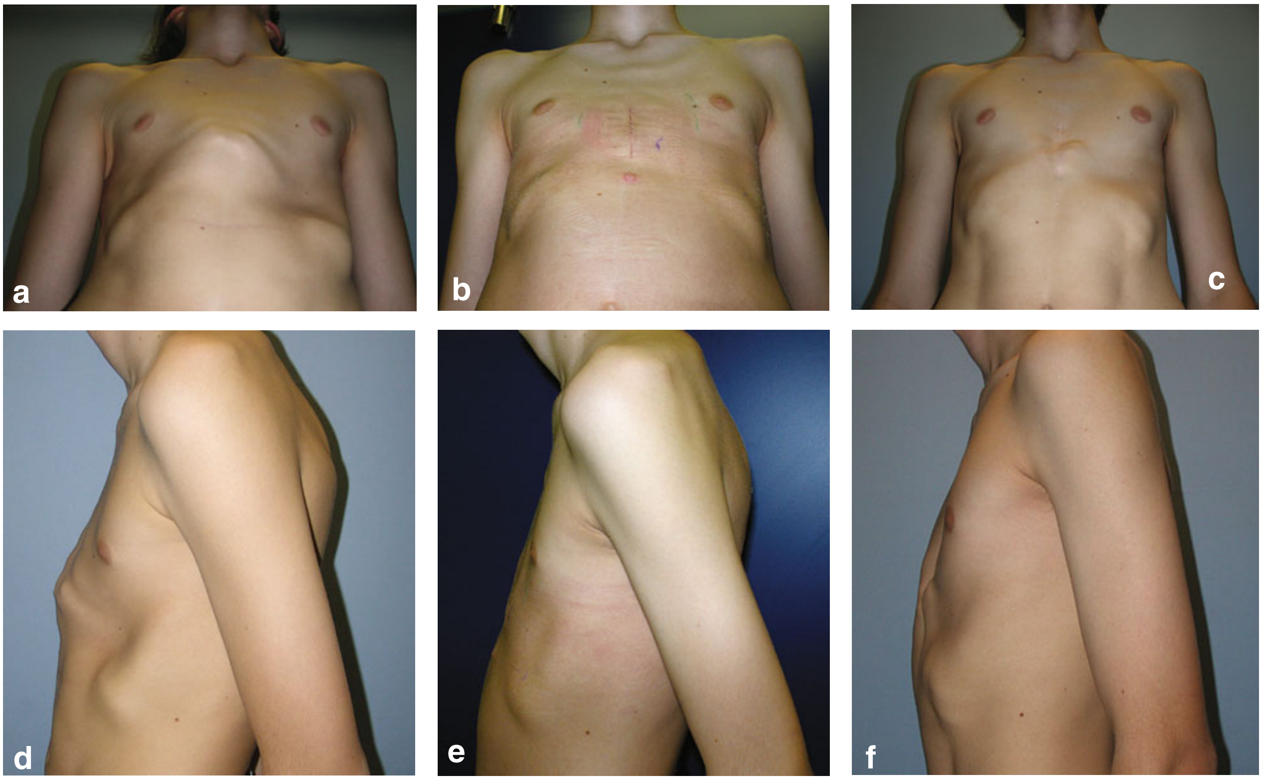

Fig. 1a and d. 16-Year-old male patient with almost symmetric keel chest deformity at the sternum area but and predominately left-sided depression of the lower anterior thoracic wall, rather unapproachable for conventional remodeling surgery. **b** and **e** Situation 8 weeks postoperatively, modified Ravitch procedure with muscle split technique (Chapter 7.2), after removal of the keel chest brace. The left-sided depression was filled up with cartilage chips resected from abundant parasternal cartilage parts. Notice the achieved and very satisfactory resulting symmetry of the lower thoracic wall. **c** and **f** Long-term follow-up 12 months after surgery with partial resorption of transplanted cartilage chip grafts but still with satisfactory result. Unfortunately some minor rib hump developed at the left paraxiphoid area, whether as a genuine relapse or eventually also caused by dislocated cartilage chips

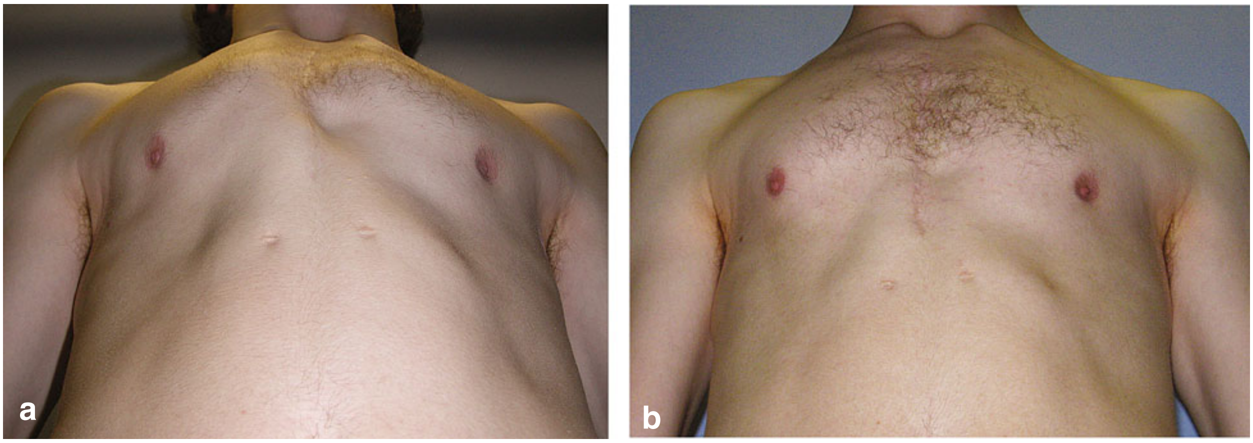

Fig. 2a. 18-Year-old boy with asymmetric keel chest deformity and a central depression between the keel ridges, additional depression at the left infrapectoral area. b Same patient 12 months after keel chest correction according to the Ravitch procedure, modified with muscle split technique, simultaneously then the central depression and the infrapectoral areas were sucessfully filled up with subcutaneously placed cartilage chip grafts, resulting in a smooth and rather symmetric skin surface

after keel chest surgery, during further growth of the body until adolescence. However, such refinements may also be necessary during keel surgery itself to augment already preexisting depressions of the thoracic wall adjacent to the keel deformity. Such accompanying depressions, if present at all, are mostly located at the lateral border of the keel-humps or extend along the inferior rib arches (Fig. 1a and d). Occasionally depressions may also be found at the central sternal region, dividing the keel into two ridges (Fig. 2a). Other depressions are not accessible or manageable by the keel remodeling surgery itself. They may present themselves rather distant from the site of surgical access, spread very laterally thus remain inaccessible for yet justifiable surgery (Fig. 3), or the convexity simply is too largely scaled to allow further invasive rib remodeling.

Furthermore, this technique of autologous cartilage chip transplantation may also be extraordinarily helpful after corrective surgery, when partial relapse of keel deformity or isolated rib hump formation occurs and depressed areas are present simultaneously. Every autologous non vascularized tissue graft and also cartilage chips may undergo unpredictable resorption or alteration of volume due to minor blood supply, infection, or dislocation, which must be part of the informed consent for those patients treated with that additional refinement.

Fig. 3. 12-Year-old female with asymmetric keel deformity and major depression at the left inframammary region. This arcuation of the lower ribs will not easily be manageable by rib remodeling procedures but may rather be filled up with autologous cartilage grafts, harvested from the left parasternal deformed rib parts. Patient is scheduled for surgery at the age of 16 or even no surgical intervention may be necessary, depending on the further development of the breasts

References

See Chapter 6.6.1.

7.4 Special after-treatment, the keel chest device

Barbara Del Frari, Anton H. Schwabegger

Compressive orthotics in former times were used for the treatment of pectus carinatum, but usually failed to therapeutic success. This was due to the fact that overgrowth of rib cartilages may be bent flat temporarily by application of continuous compression lasting for several months [4, 6]. Usually the overgrowth of rib cartilages in length causing the deformity may not be treatable just by compression, especially in adolescents and adults. On the other hand, the experiences of orthopedics in the construction of such orthotic compressive chest braces are available to apply such devices just in the postoperative keel chest treatment. Such an adjunctive brace should serve for immobilization and lowering the respiratory excursions of the chest wall and sternum during the healing process. That kind of brace changed its task from a primary treatment device to a secondary supportive treatment tool to maintain the surgically achieved shape and to enable early healing of mobilized sternum bone parts and rib cartilages. Furthermore, due to restriction of excessive inspiratory excursions it avoids rupture of deeply set sutures, such as perichondral reefing or muscle sutures. Postoperatively after keel chest correction with the conventional Ravitch procedure (Chapter 7.1) or the modified Innsbruck protocol (Chapter 7.2) we routinely first apply a circumferential elastic compression dressing (Fig. 1) with an adhesive under-surface for the fixation and compression of a steel wool padding above the area of remodeling to immobilize the chest wall. At about the third postoperative day, all patients receive an individually manufactured "custom-made keel chest brace" with moderate compression that is applied in a sagittal direction (Fig. 2a–c). The compression brace has to be worn for at least 23 h/day for about 6–8 weeks to guarantee healing continuous immobilization and compression of the shaped area of the thoracic wall [7, 8]. The purpose of the brace is to provide further stability additionally to perichondral reefing sutures and, occasionally applied, bioabsorbable osteosynthesis. The brace eliminates postoperative respiration movements at the thorax, which furthermore reduces pain, but still permits deep respiratory excursions during breathing therapy postoperatively and later on after demission physical exercise by abdominal breathing using the diaphragm.

A silicone containing foamy sheet (Fig. 3a, b) is attached to the anterior pad encompassing the area of remodeling and the presternal skin scar to prevent the development of a hypertrophic scar (Chapter 12.2). So far in our series of surgical keel chest with ensuing bracing hypertrophic scarring was apparent in no case. In two particular cases even with precedent open-heart surgery subsequently a hypertrophic scar developed and remained as a clearly visible stain. Years thereafter keel chest surgery was performed using the same access, however with excision of the whole length of the scar for intentional scar correction. The resulting scar after keel chest correction and ensuing brace compression therapy for 2 months led to a much better appearance than the remaining, also excised and equally surgically treated scar at the sternum, however lying beyond the reach of silicone pad com-

Fig. 1. Circumferential elastic compression with self-adhesive dressing, steel wool bolster beneath the area of remodeling to provide with smooth compression

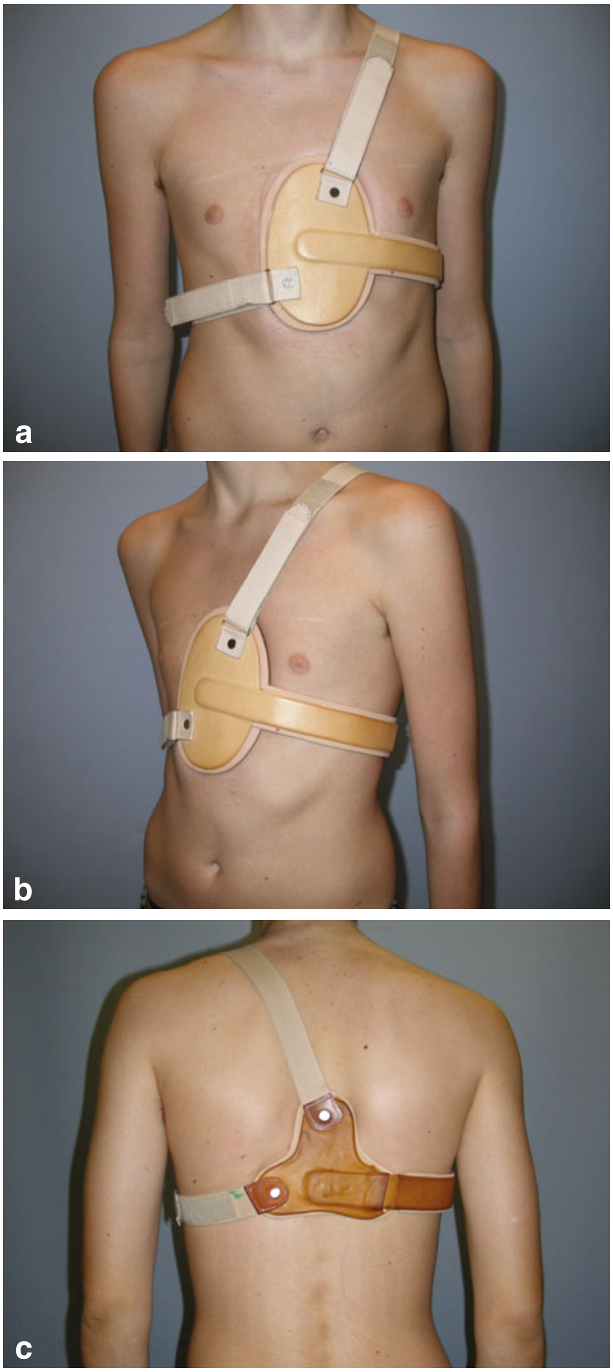

Fig. 2a. Anterior aspect of a custom-made keel chest brace well fitting and covering the area of surgical remodeling of the affected skeletal structures. Notice the metal wing at the left side and the adjustable flexible band at the right side. **b** Lateral aspect of the same brace, the metal wing smoothly adapted (custom-made) to the patient's individual chest shape. **c** Dorsal aspect depicting the counter-part of pad for harmonic balance of the pressure applied in a sagittal direction and protection of the skin against undue compression along the dorsal spinal processes

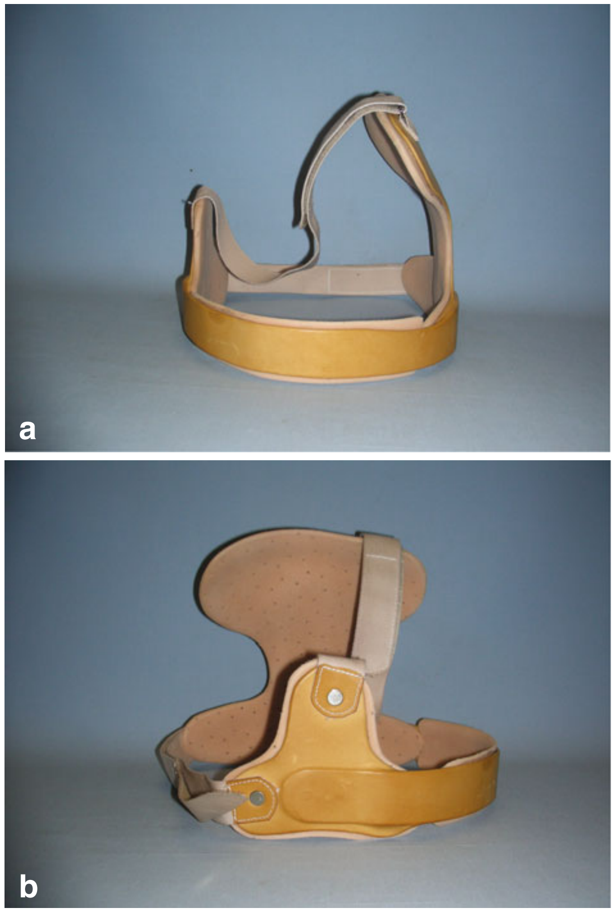

Fig. 3a. Lateral (right) aspect of a custom-made keel chest brace ready for use, showing a steel wing (front) covered with skin compatible leather surface. **b** Dorsal aspect to depict the anterior compressive pad for maintaining the shape of thoracic wall achieved through surgery, which furthermore is covered with a silicone sheet to reduce scar formation and above that to prevent hypertrophic scarring

pression (Fig. 4). One might argue that the different ages of both patients at heart and then at keel chest surgery could have been responsible for the different developments of the appearance of these scars, but on the other hand the curative effect of compression on hypertrophic scars is well known and among others [1, 9] an established way of therapy [2, 3, 5]. As clearly visible in Fig. 4, the exactly circumscribed flat and pale segment within a very long though fresh looking and unsightly scar may evidently be attributed only to the beneficial effect of the compression pad that exactly covered this now pleasantly looking part of the scar.

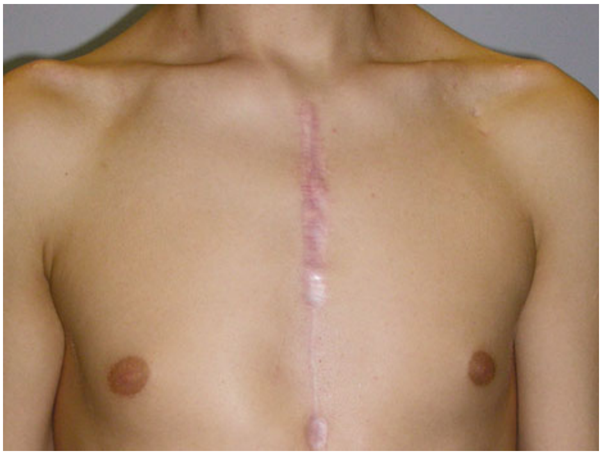

Fig. 4. Keel chest surgery and simultaneous scar correction performed many years after heart surgery at childhood. Notice the clear demarcation of the area which underwent compression by the pad of the keel chest brace (lower part of scar with pale surface) versus the sections which remained free of pressure remote from the pad (xiphoid and cranial part of sternum)

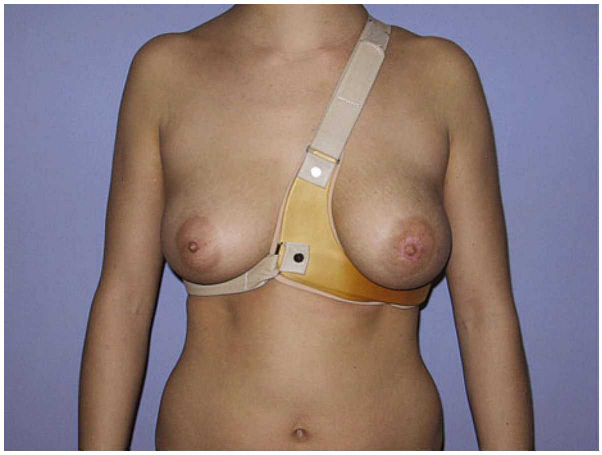

Fig. 6. Particular design for an adult female, who underwent unilateral chondrotomies through a single inframammary incision on the left side. The compressive pad reaches also up to the décolleté region, where chondrotomies were performed from a subcutaneous and transmuscular approach through that inframammary incision

In our series of more than 60 patients who underwent keel chest surgery since the utilization of the keel chest brace no hypertrophic scarring was apparent within a range of follow-up from 6 weeks to 36 months.

Especially in females and herein in asymmetric cases with surgical access along the inframammary crease, specially designed braces (Figs. 5 and 6) can be manufactured for adequate inframammary compression, extending up into the décolleté.

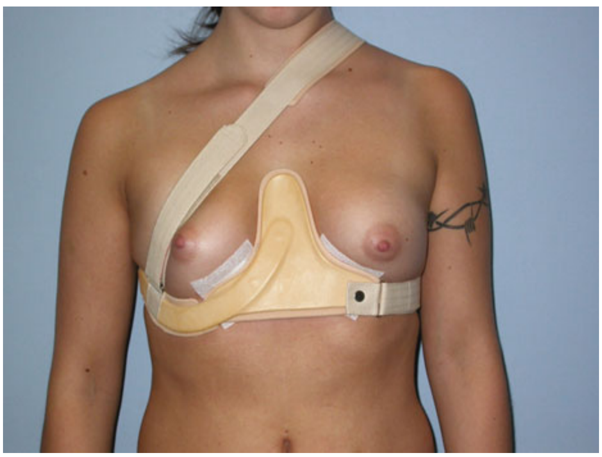

Fig. 5. Specially designed brace for a female who had bilateral incisions for keel chest surgery at the parasternal inframammary crease including horizontal sternum osteotomy

There were minor postoperative complications such as epidermal skin irritations and formation of blisters caused by inappropriate initial pressure from the keel brace in singular cases (Chapter 12.1). In one of our cases unfortunately 1 week postoperatively and 2 days after explantation of the peridural catheter the patient developed meningitis, caused by skin bacteria. The elastic compression dressing, obligatory in every keel chest patient immediately applied after wound closure, was accused to eventually have deteriorated the detection of local skin infection with ensuing penetration of the infection into the dural surfaces. That assumption could not be verified, however every location (skin perforation) of peridural catheter implantation at the back should be excluded from compressive dressings for early detectability of any irritation.

The custom-made keel chest brace usually is manufactured and available within 2–3 days after measurements, which may take place at the second to third postoperative day. The patients are dismissed not before the brace fits well, then are obliged to sleep on the back for 6–8 weeks postoperatively, as long as wearing of the brace is necessary. The period of application depends primarily on the extent of the pre-existing keel deformity, the extent of surgery, and the overall morphology of the patient. Athletic tall patients with excessive deformity may even require longer periods of bracing, whereas in unilateral deformities in youths 4 week may be sufficient. However, taking into consideration the potential development of hypertrophic scars it may be wise in every case to suggest bracing for 6 weeks at least.

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