Diagnostics

3

3.1 Photography

Anton H. Schwabegger

"A picture is worth a thousand words."

Outcome documentation and course observation of plastic surgical interventions are described often circumstantially; however, in addition to the backup of photos and in functional reconstructions with movies, these interventions can be documented comprehensively. For decades already reconstructive surgeons rely on photography as a means for documentation of patients, assessment of results, teaching, and publications. Nowadays, with the evolution of digital depiction many tasks in storage, post-processing, and visualization are made much easier, thus standardization is a requisite for academic research [1] and to obtain informed consent from patients. Usually patients show preference to the use of non-identifiable photographs, as long as they serve for medical documentation, teaching or presentations on meetings, and congresses, whereas they do less accept distribution of pictures on the Internet [2, 3]. Therefore, also a written consent, containing the detailed purposes of taking photographs should be obtained from all patients before any photography.

A documentation of the initial situation in reconstructive or remodeling surgery serves both the planning of, at times, complex intervention and also for the preoperative information for the patients. The documentation of thoracic wall deformities by means of photography succeeds very well if certain criteria of standardized photo techniques are adhered. This standardization is an absolute requirement to enable documentation of the course of the variations through the intervention traceable and to compare the preoperative situs with the postoperative result understandably [4, 5]. Photographs such as these can be stored digitalized in a computer and can be retrieved via network in any examination room on demand during consultation or even teaching. Because in such corrective interventions at body contour often only an amelioration of the extent of the deformity is attainable and in spite of substantially best information communicated to the patient, his expectation of a perfect shape cannot be achieved. In these cases, an objective documentation by means of photography may be very helpful in the argumentation of differences of opinion or disproportionate expectations (Chapter 3.6). Herewith and during the first conversation, vivid information at hand of photographs of operated cases can already help the patient to estimate the feasibility of corrections realistically and may limit his expectations. Also the photographic presentation at hand of the results of treatment alternatives or other surgical methods can help the patient to come to a well-tolerated decision. By reason of published reports in glossy prints or semi-medical magazines many patients already reject the use of any silicone implant beforehand. Such misinformed and irritated patients then can become convinced, however at hand of already documented results of alternative interventions, that minor invasive surgery using, e.g., alloplastic material or autologous tissue may yield sometimes better results than more invasive modern interventions. Through photo documentation, the aspect of scars to be expected can be better imagined and explained.

Furthermore, an exact photographic documentation also serves for quality improvement and represents a valuable and reliable tool for quality control. Photography substantially also serves for teaching the treating nurses and students. It is a helpful instrument in training and continued education within departments as well as in interdisciplinary advanced training and on congresses. During demonstration and teaching therewith no patient with such a deformity, usually embarrassed and plagued by shame, needs to undress and expose face-to-face with other medical personnel or students. On the other hand, the presentation of photo documentation, even if comprehensively complete, cannot replace the personal conversation with the patient, its exact case history inquiry and psychological examination, but rather will supplement such a consultation ideally.

In the question and the setting of indication to any surgical intervention as a curative treatment with the costs covered by the health insurance companies, photography often also serves as a sup-

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plementary decision criterion. Finally a chronologic documentation using photography is part of the medical record and in cases of medico-legal issues with conflicts between patient and physician may serve as an objective evidence of course and results.
Standardized constants in photography of the thoracic wall deformities are:

- distance from camera to patient;
- angle of camera to patient; and
- removal of clothing, underwear, and noticeable jewellery from the torso.

Photos are made preoperatively and postoperatively up to 1 year of follow-up:

- 0° exact anteriorly (Fig. 1),
- 90° angled laterally from the right side (Fig. 2),
- 90° angled laterally from the left side (Fig. 3),
- 45° angled laterally from the right side (Fig. 4),
- 45 angled laterally from the left side (Fig. 5),
- from above (Fig. 6), and
- from beneath (Fig. 7).

In addition, specially angled photos are made in particular deformities or, e.g., asymmetry of the female breast:

- from above and beneath (Fig. 8–10) and
- torso bent over to depict the difference of volume or distortion of the breasts (Fig. 11).

In addition, specially angled photos are made in particular deformities like Poland's-syndrome to document the extent of deformity and to depict functional deficits during muscular contraction based on hypoplastic skeletal structures.

- multiple functional photos taken without and with muscular contraction, individually dependent on the extent and type of deformity (Fig. 12 and Fig. 13a–k).

Photos of the initial preoperative situation are compared with the immediate postsurgical appearance to document the immediate morphologic and aesthetic success of an intervention exactly. In the further follow-up examinations, photos are taken after suture removal, furthermore after 3, 6 and 12 months in order to observe the course of the result objectively and to recognize any possible morphologic variations as a side-effect for example due to physical growth. These photos then serve, together with chest X-rays and the measurements taken with the Thorax-caliper (Chapter 3.2) as multimodal documentation and serve to fulfil the increasing demand for quality control and quality security over a longer term. In consequence, such long-termed follow-up documentation serves for the scientific editing, with reliable and valuable verification of results and the option to facilitate peer-reviewed studies [1] and publication of meaningful and permanently successful or also less successful interventions. Particularly the depiction and description of undesirable results or long-term complications serve the progress and the selection of meaningful measures out of a multitude of most varied therapeutic measures or therapy attempts.

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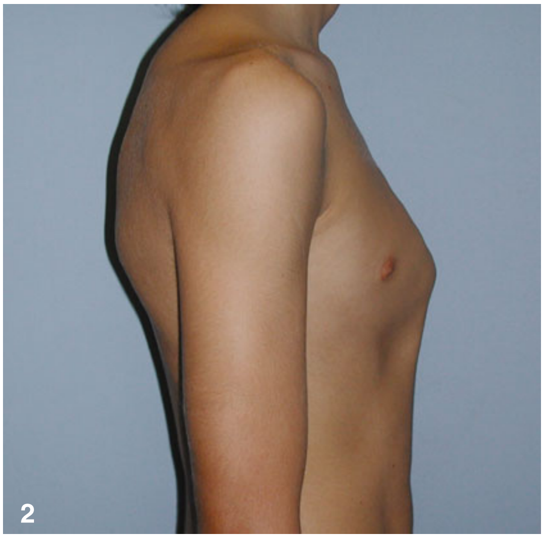
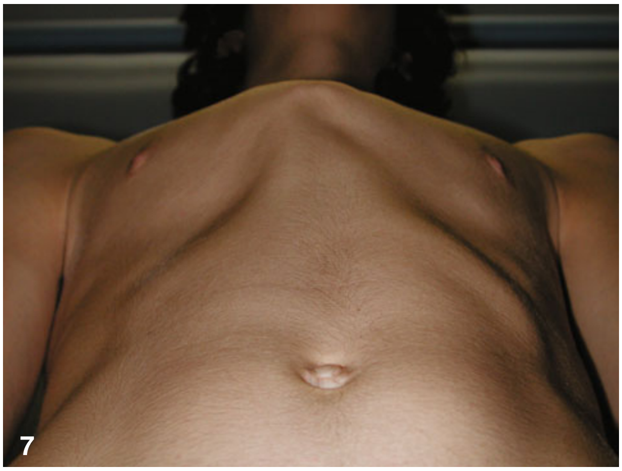


Figs. 1–6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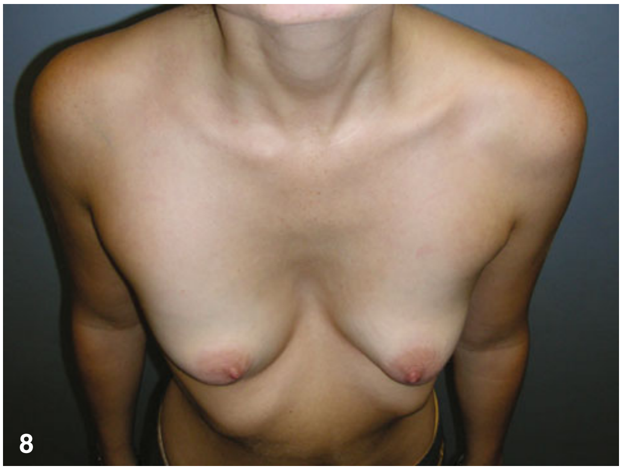
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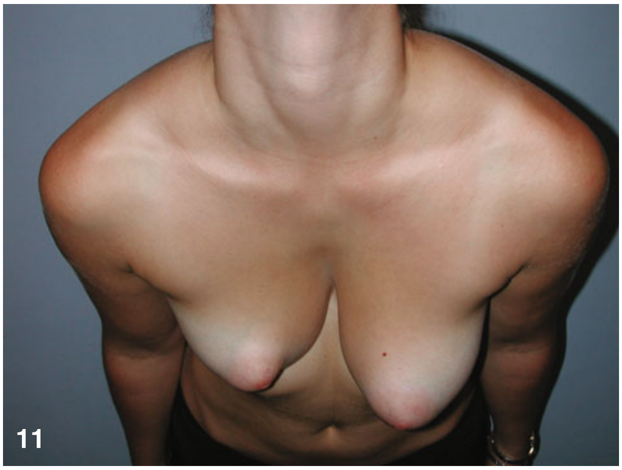
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Figs. 7–12

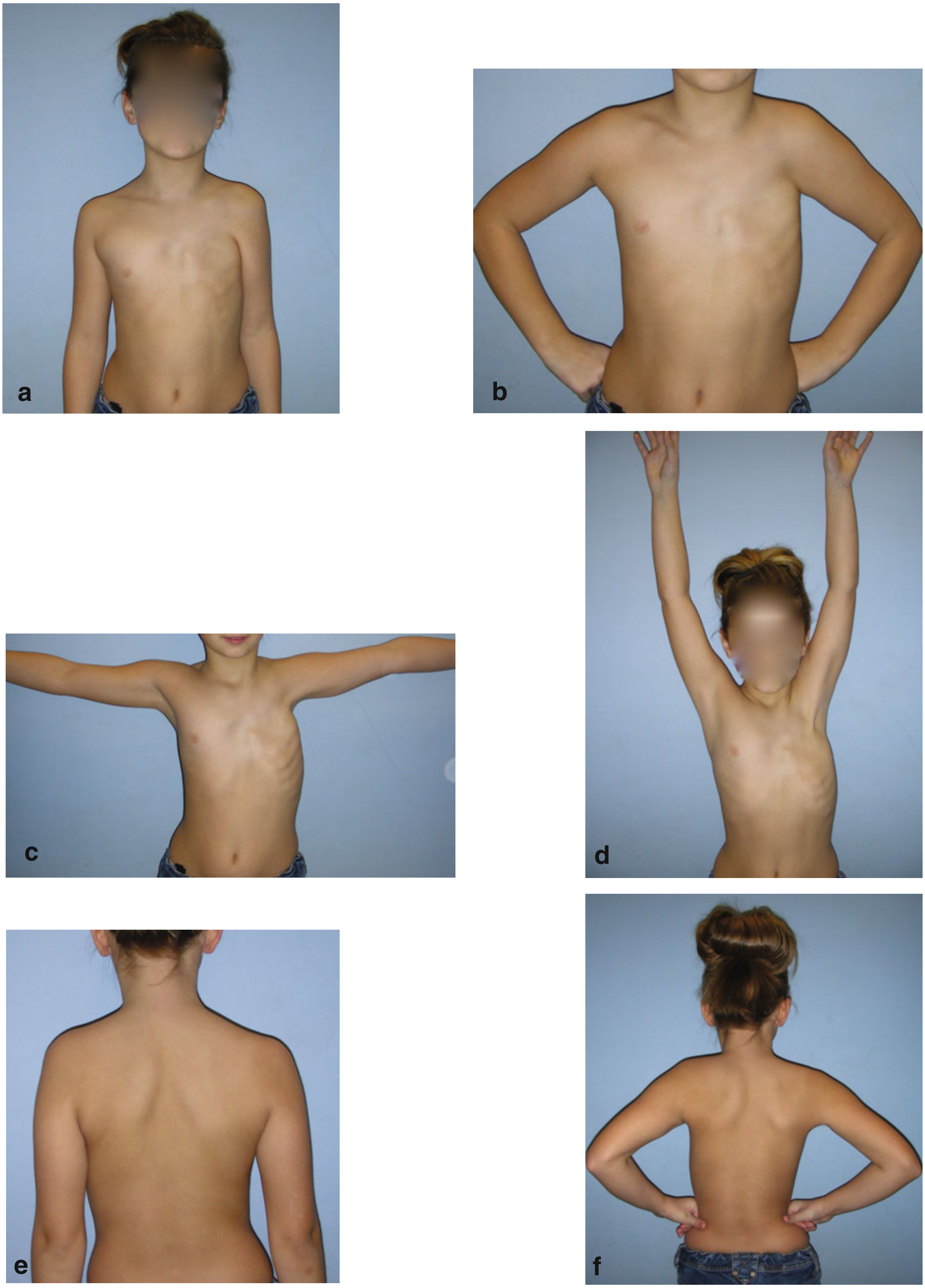


Fig. 13a–f

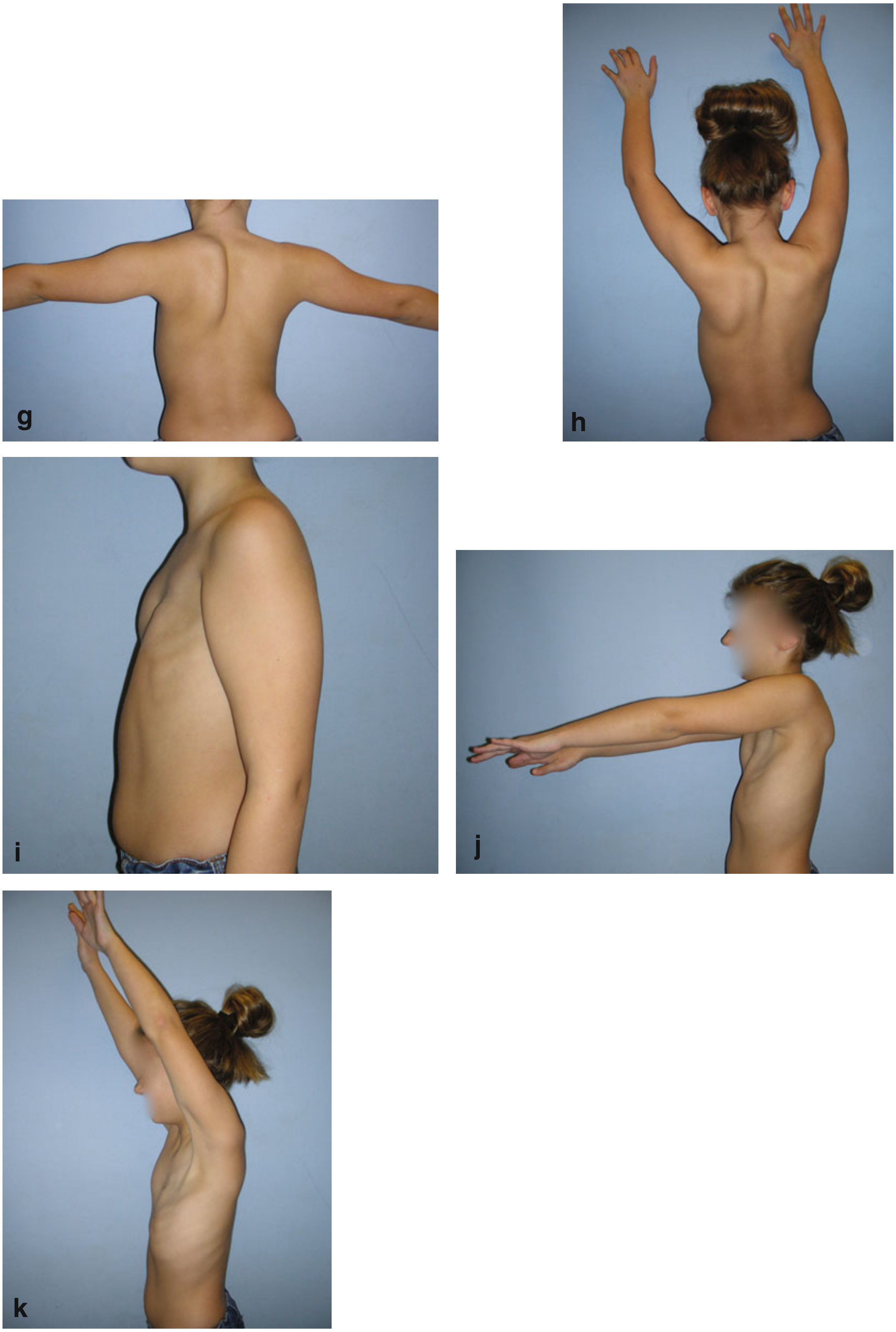


Fig. 13g–k

3.2 Thorax-caliper

Anton H. Schwabegger

Until now, for the documentation of results of the morphologic variations after thoracoplasties photography as a standard measure still remains unsurpassed. Unfortunately, therewith only a planar, two-dimensional image and documentation succeeds, even if pictures are taken in different planes and angles (Chapter 3.1). A far better representation and documentation of the variations of the intra- and extrathoracal diameter in a certain plain, above all in the funnel chest deformity, succeed with computer tomography and therefrom with calculation of the pectus severity index (PSI). This, also as Haller index (Chapter 3.4) well-known reading [6] corresponds only to the internal diameters of the thoracic cavity and serves for the evaluation if a thoracoplasty caused its expansion. On the other hand, this index in certain institutions also primarily substantiates the indication setting for the surgical correction of the funnel chest deformity with remodeling procedures for medical reasons, above all, if restrictions of cardial or pulmonary functions exist. The PSI therefore predominantly serves for preoperative diagnostics and documentation in the funnel chest deformity but hardly in its postoperative course observation and documentation. Furthermore, it finds no place in the diagnostics, indication setting, and follow-up documentation in all other thoracic wall deformities, like Poland's syndrome or keel chest deformity. Using the method of the surface scanning, represented in Chapter 13, the outstanding possibility of an exact 3D-depiction and verification of the thoracic wall morphology, and ensuing postoperative results by calculation of variations of volumes exist indeed [4, 8, 10]. However, disadvantageously an altered nourishment condition may interfere in a false positive or negative extent, causing incorrect optically measured result. Moreover this technology still remains relatively cost-intensive until now.

A further anthropometric method measuring body surfaces and postoperative variations, used in funnel chest patients, is the pectus excavatum anthropometric index [2] (PEX-AI), developed at the Department of Thoracic Surgery of the Heart Institute, Sao Paulo School of Medicine. In order to calculate this index, one requires two indicators. The indicator A on the one hand describes the largest antero-posterior distance; and the indicator B on the other hand measures the innermost point of the skin surface of the pectus excavatum deformity. The measurements are determined in supine position on a flat table and during deep inspiration. In patients with a PEX-AI below 0.12 no deformity subsists and can be estimated as naturally shaped, whereas in contrast to patients with a PEX-AI above 0.12 a pectus excavatum deformity may be demonstrated. Also this method of measurement requires technically expensive devices and relatively much time.

Furthermore Chang et al. [3] in 2009 described another noninvasive anthropometric tool of pre- and postoperative measurement using thermal plastic strips. Using that molding, they were able to follow up the postoperative course even after removal of the pectus bar and could show a significant decrease of the surgically achieved modeling of the anterior thoracic wall in pectus excavatum deformity, after removal of the metal

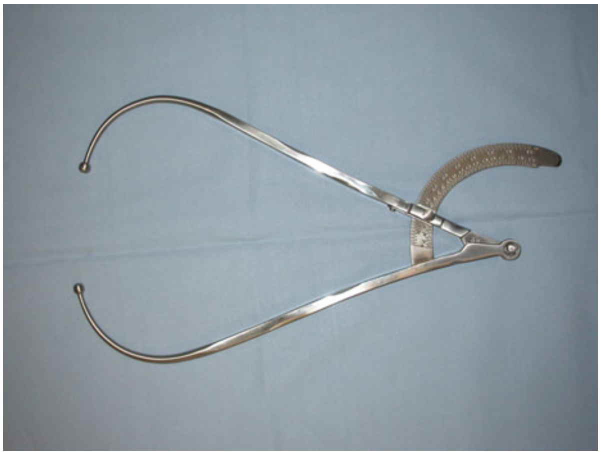
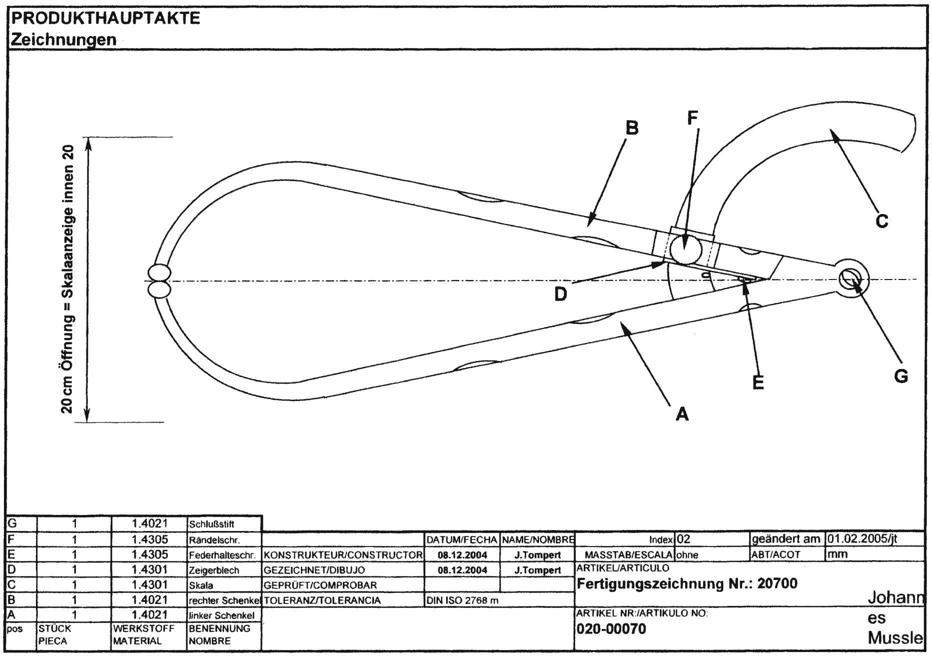


Fig. 1. Thorax-caliper made of steel, with a scale gauged in inches and centimeters. For validity of measurements the spheric ends of the branches must be moderately pressed against skeletal subcutaneous structures



pos	STÜCK PIECA	WERKSTOFF MATERIAL	BENENNUNG NOMBRE
G	1	1.4021	Schlußstift
F	1	1.4305	Rändelschr.
E	1	1.4305	Federhalteschr.
D	1	1.4301	Zeigerblech
C	1	1.4301	Skala
B	1	1.4021	rechter Schenkel
A	1	1.4021	linker Schenkel

Fig. 2. Construction outline of the thorax-caliper

strut. They found this tool very helpful in further planning of the exact site of pectus bar implantation.

However, alternatively to these techniques another noninvasive method of measuring external diameters is available. It represents a very economical, effective method, meaning only slightest expense, equivalent and in some aspects even superior to the above-mentioned methods in documenting a situs or the course of morphologic variations objectively. It concerns a modification of the pelvis-caliper commonly used in obstetrics and mentioned for the use in pectus excavatum surgery by Haller in 1978 [5]. Ebstein successfully used it already in 1882 [7] for the measurement of thoracic diameters. This above-mentioned pelvis-caliper nowadays was adapted and newly constructed for the application at the thorax (Fig. 1). It is named thorax-caliper and distributed by the company MedXpertTM (MedXpert GmbH, Heitersheim, Germany), which developed this device of avail (Fig. 2).

The basic idea of the development of this thoracic caliper was to create a simple and easily applicable device, which on the one hand circumvents X-ray radiation given by the CT investigation technology, and on the other hand is consistently usable in the clinical daily routine. For the surgeon or the investigator as well as for the patient, this method represents both an objective follow-up observation and an excellent tool for documentation of the outcome quality of shape remodeling. This method of investigation is independent from the person of examiner and the results are always reproducible, also the logistical efforts to organize cost-intensive CT investigations can be circumvented. At times of ever increasing costs in health care, such a simple, cheap, and efficient method for the measurement of thoracic wall deformities can be only of advantage.

Very narrow sagittal diameters on the other hand, previously documented with the thoracic caliper, can yield evidence that the intrathoracic diameter already leads to displacement of the intrathoracal organs and therewith further investigations like computer tomography are indicated necessarily.

3.2.1 Technique of measurement

During measurement, the patient stands upright, with arms hanging downward and remains in loose expirium. The measurement points at the thoracic wall for the transversal diameter are situated at the lateral thoracic wall, at the level of the nipples, exactly between the anterior and posterior axillary line (Fig. 3). Herewith the metallic spheres of the caliper branches are attached to the ribs with moderate pressure in order to grasp fewer soft parts however more the skeletal diameter structures and diameters. The measurement points for the more important sagittal diameters are also situated at the level of the nipples. At the back and at the same level a branch of the caliper is put on a spinal process (Figs. 4–6). The choice of the anterior measurement point depends on which deformity exists, moreover also on the sex of the patient. The diameters obtained with the thorax-caliper can be read directly on a gauged scale fixed at the caliper in centimeters and inches (Fig. 1).

In male patients with symmetric or only slightly asymmetric deformities the second (anterior) caliper branch to scale the sagittal diameter is placed at the level of the nipples, exactly in a median line above the sternum. If asymmetry or a more rare atypical

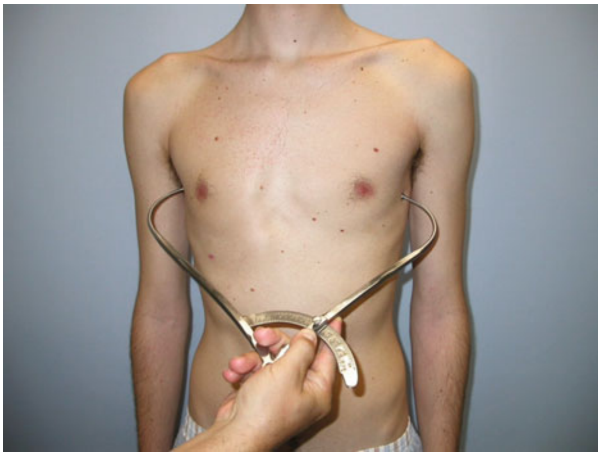
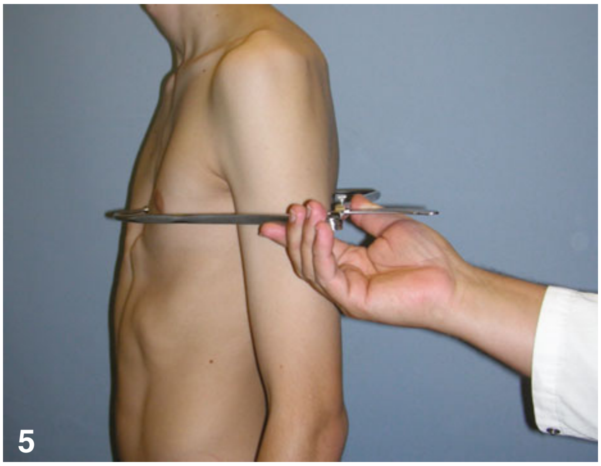
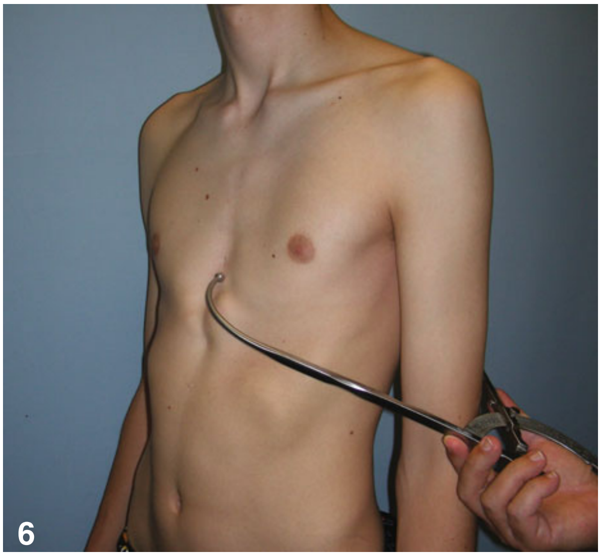


Fig. 3. Transversal measurement taken at a horizontal level of the nipples between the anterior and posterior axillary line



Figs. 4 and 5. Sagittal measurement taken at the same level as the transversal measurement



Figs. 6 and 7. In cases with irregular surface of the deformity, measurements should be taken at the deepest depression and at the highest point deformity is existent, setting of additional measurement points is recommended, e.g., at the deepest depression (Fig. 6) and highest elevations of the sternum or ribs deformity (Fig. 7) whereby the measurements must always be taken in a standardized manner in a horizontal plane.

In patients with ptotic or asymmetric breast, the sagittal measurement cannot be carried out at the level of sagged or asymmetrically positioned nipples. The highest point of a keel and the deepest point of a funnel deformity then must be measured and documented, respectively, irrelevant from the level of the nipples, however, in a horizontal plane anyway. By means of phototographic documentation, which is carried out in every patient, the location of measurement points can be reviewed retrospectively, where they were taken preoperatively. In order to include the influence of growth and weight alteration on the variations of the chest in youthful patients, also these variations are documented by means of the parameters size, weight,

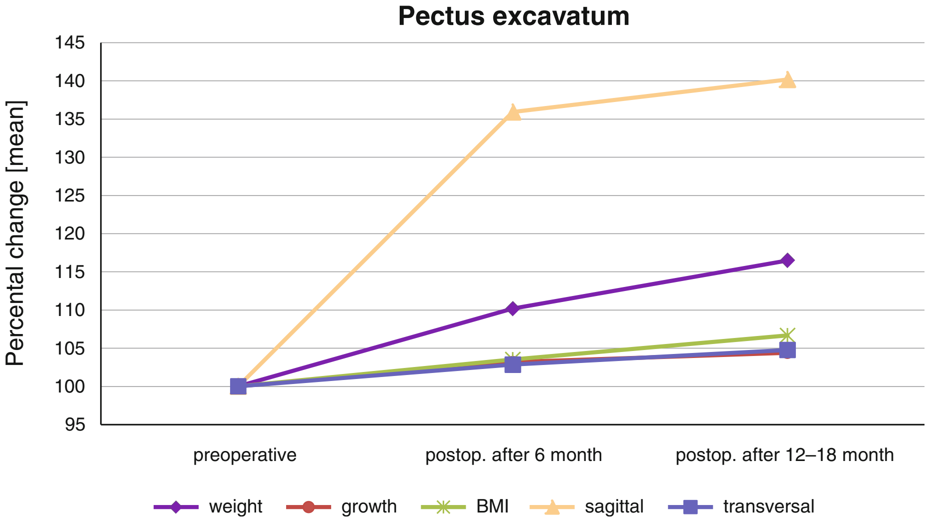


Fig. 8. Measurements result of alterations of the sagittal and transversal diameters in 24 patients with funnel chest deformity from preoperative situs to long-term postoperative follow-up, set in relation to change in weight and height

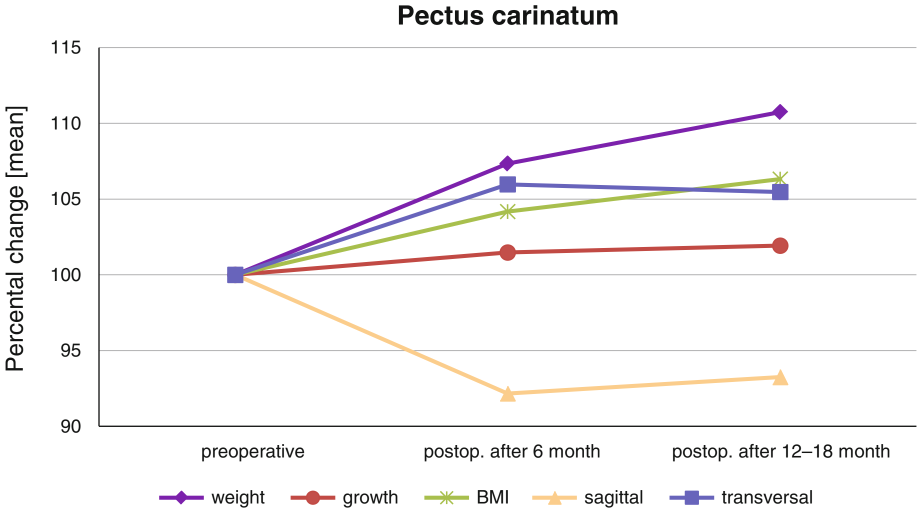


Fig. 9. Measurements result of alterations of the sagittal and transversal diameters in 23 patients with keel chest deformity from preoperative situs to long-term postoperative follow-up, set in relation to change in weight and height

and BMI over the defined period of follow-up. Therefore variations in proportion during growth can be compared and can be brought in reference to the indexes of the changing thoracic diameters (Figs. 8 and 9) statistics.

In a retrospective course study prepared with statistical methods, the thorax-caliper has proved itself as extremely useful to exactly compare the course of preoperative to immediate postoperative situations as well as to document the long-term course [1]. The measurement with the thorax-caliper proved itself substantially superior compared to the remaining measurement methods, because it allows a close-meshed, anytime repeatable, very economical, easily learnable, painless, and above all noninvasive survey. The thorax-caliper though cannot replace a preoperative imaging of the intrathoracal situs necessary in certain cases, yet the indications for these investigation techniques are anyway different. The CT investigation on the other hand should not be requisitioned for the pure course observation because of the radiation burden and its costs.

For the patient himself, a rapid and easily available course observation of the postoperative result ensues, whose positive subjective estimation through the patient substantially depends on visibility and objectifiable results. Through the straightforward measurement with the thorax-caliper, these results are easily understandable for the patient and in this manner perhaps contribute to promotion of the recovery process, within which the psychic component may not be disregarded. Positive messages, in the sense of an improvement of the measurable values, obtainable through the thorax-caliper will allow an essential influence on the psychic contentment and the quality of life of the affected patients for certain [9] (Chapter 3.6).

Especially for the patient, the investigation itself works simply and is feasible without any preparation. For the investigator, under the prerequisite that he complies with the given measurement criteria, no special education or sophisticated instruction is necessary.

3.2.2 Conclusion

Comprehensively the measurement with the thorax-caliper serves less to the indication setting for surgery, but rather enables a straightforward documentation and course observation as well as it represents a supplement to photographic documentation in the sense of quality control and quality securing of such remodeling surgical interventions.

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3.3 Radiologic diagnostics

Michael Rieger

Pathologic processes that may involve the chest wall include congenital and developmental anomalies, inflammatory and infectious diseases, and soft-tissue or bone tumors. Many of theses processes have characteristic radiologic appearances that allow already definitive diagnosis. Sternal deformities on the one hand can be visualized with conventional radiography alone, on the other hand their severity may be quantified with computed tomography (CT).

3.3.1 Conventional radiographs

In funnel chest (pectus excavatum), the most common congenital thoracic deformity, the sternum is depressed so that the ribs on each side seem to protrude more anteriorly than the sternum itself. This sternal and cartilaginous depression reduces the prevertebral space, resulting in leftward displacement and axial rotation of the heart-simulating cardiomegaly, which can be depicted in the posteroanterior chest radiography (Fig. 1), as well as reduction of the space occupied by the left lung. The displaced pulmonary vascularity and obscured right cardiac border resemble a right middle lobe process. The posterior ribs run horizontally, whereas the anterior ribs show a more oblique course downward. The degree of a sternal depression is easily visualized at lateral radiography (Fig. 2), but not in the posteroanterior view.

Keel chest (pectus carinatum) is a deformity of the chest wall in which the sternum exhibits abnormal protrusion anteriorly (Fig. 3). A relatively large sagittal diameter is observed on lateral radiographs. On frontal radiographs, the lateral portion of each rib appears elongated and straight downward [1, 2].

Funnel and keel chest can be diagnosed on conventional radiographs; however, the lateral radiography clearly depicts the reduced or enlarged sagittal diameter in these congenital deformities, whereas the posteroanterior chest radiography shows only indirect signs of a present skeletal deformity, like displaced heart or lung anomaly. The degree and characterization of the deformity, the relationship of the sternum to the bony part of the ribs, and their cartilages as well as the deviation of these structures in various planes thus may be much better depicted with CT.

3.3.2 CT-scan

The rapid development of helical CT has resulted in exciting new applications for CT. The technical enhancements that multi-detector row computed tomography (MDCT) devices have experienced over the past years have brought significant technical progress and

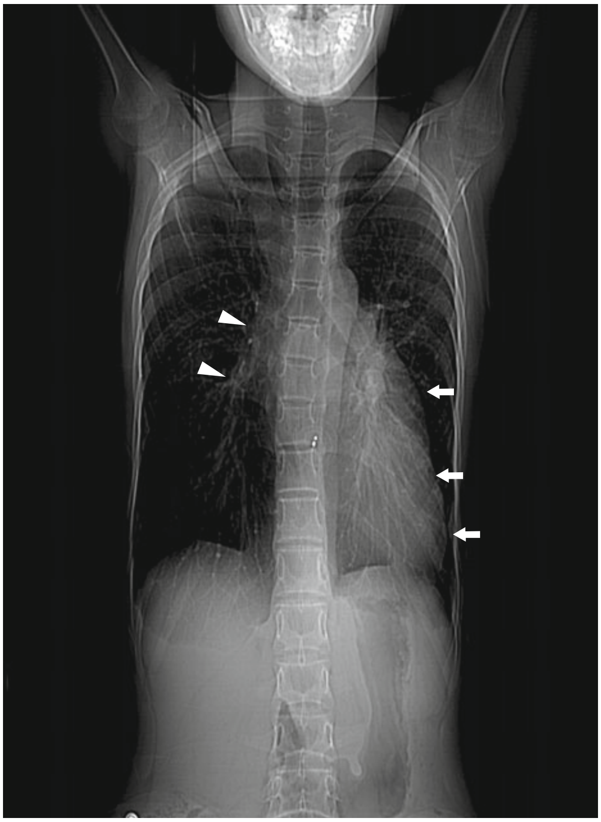

Fig. 1. Pectus excavatum in a 14-year-old girl. Coronal CT scout of the chest shows leftward displacement of the heart (arrows). Because of the rotation of the heart the pulmonary arteries of the right side are depicted prominently (arrowheads)

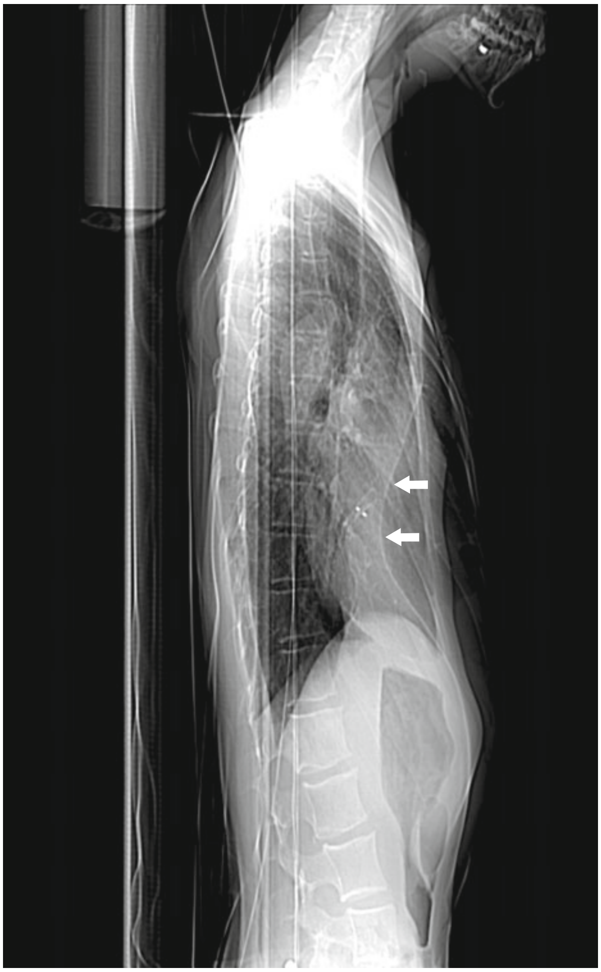

Fig. 2. Pectus excavatum in a 14-year-old girl (same patient as in Fig. 1). Sagittal CT scout of the chest demonstrates severe depression of the sternum (arrows)

influence in all fields of diagnostic radiology. Equipped with multiple row detector arrays resulting in increased longitudinal volume coverage and thin collimation, MDCT provides a volumetric scan of the entire thorax in only one short breath hold (less than 10 s). This provides true isotropic as small as 0.35 mm resolution in all directions with reduced artifacts due to cardiac and respiratory motions. With volumetric data acquisition, it is now possible to reconstruct contiguous thin-section images as well as volume rendered and multiplanar reformatted images. Using a 64-row MDCT for example the quality of coronal and sagittal reformations is comparable to axial images. Coronal reformations on 64-row MDCT show substantial agreement with axial images in the evaluation of thoracic abnormalities [3].

Fig. 3. Pectus carinatum (keel chest) deformity. An extended sagittal diameter is present, with protrusion of the sternum

Because of the potential for malignancy, children who have lumps palpated in the chest wall at physical examination are often referred for cross-sectional imaging. It has been shown that in most of these children, the cause of the lump is a benign variation in the anatomy of the anterior chest wall, which has a number of functions that when altered can result in a variety of pathologic processes. Because the chest wall provides a structural framework that is the basis for physiologic motion of the pulmonary system, deformity of the chest wall can result in both restrictive and obstructive lung diseases. The space in the superior mediastinum normally is limited, confined by the sternum superiorly and the vertebral column posteriorly. Abnormal thoracic configuration can result in further reduction in the volume of this space or in alteration in the anatomic relationship between the trachea and adjacent structures. Both mechanisms can result in displacement and compression of the mediastinal structures (Fig. 4). The most common abnormalities of chest wall configuration result from overgrowth of the length of costal cartilages which occurs in utero and does not allow the sternum to come forward with inhalation [4] (Fig. 5). Although

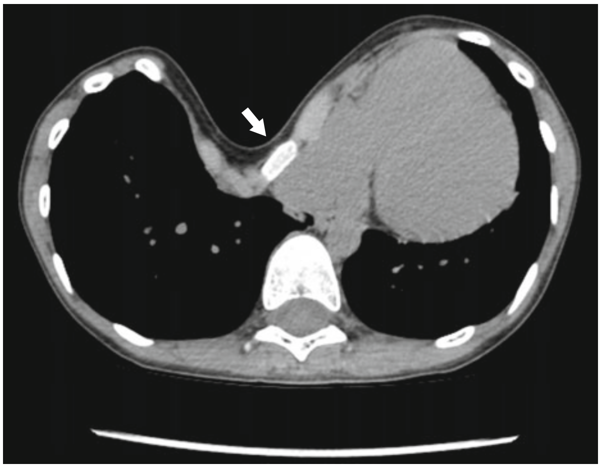

Fig. 4. Pectus excavatum in a 14-year-old girl (same patient as in Fig. 1). Axial CT scan shows anterior chest wall to be concave. The midline chest wall (arrow) is located much more posteriorly than the more lateral chest wall. The heart is hard-pressed and toward left lateral displaced

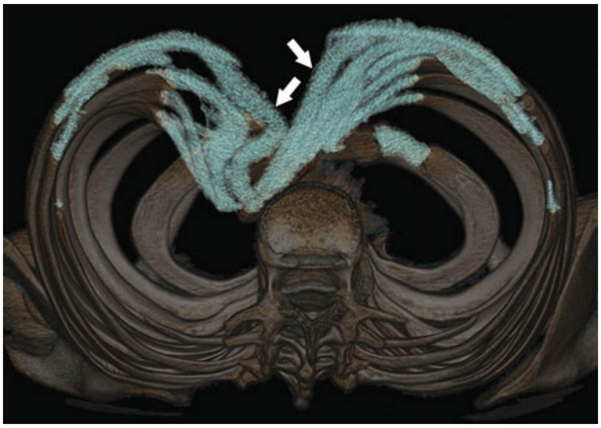

Fig. 5. Pectus excavatum in a 14-year-old girl (same patient as in Fig. 1). Oblique transversal 3D volume rendering reconstruction depicts the deformity of the chest wall with depression of the sternum and especially from an overgrowth of the length of costal cartilages (arrows)

most problems that are due to these deformities are aesthetic (Fig. 6), pectus excavatum deformities can cause chest pain, fatigability, dyspnea on exertion, palpitations, and restrictive lung disease. Depending on the extent of deformity, various methods of surgical repair to be performed are available [5].

For the purpose of providing information to the surgeons, MDCT allows exact pre-op measurement of the deformed bony and cartilaginous rib cage and thus supports the operative correction and placement of reconstructive maneuvers. A transverse section of the MDCT data may be used exemplarily to compute the "pectus index" advocated by Haller et al. for quantification of the chest wall defect in pectus excavatum [6]. A transverse section at the level of the greatest severity of the defect may be used to determine this ratio of the lateral thoracic diameter to the sagittal diameter as a ratio of more than 3.25 is estimated as pathologic. In addition, MDCT depicts the displacement of mediastinal structures caused by the abnormal thoracic configuration and their consecutive probable impairment. Furthermore, pulmonary changes like areas of emphysema or hypoventilation can be depicted within the same MDCT examination, which offers therefore a comprehensive workup of patients suffering from congenital thoracic wall deformities.

Fig. 6. Pectus excavatum in a 14-year-old girl (same patient as in Fig. 1). 3D volume rendering reconstruction with a low threshold showing the patient's skin surface depicts the cosmetic problem in this patient due to this deformity of the chest wall

Using a recent CT device and a low dose protocol the effective radiation dose of a CT examination of the chest is about 3.2 mSv with the highest values for the breast (about 8.1 mSv) and nearly no uterus radiation.

3.3.3 Three-dimensional volume rendering CT reconstruction

Nowadays the common volume rendering (VR) technique makes use of the entire data set and thus conveys more detailed information than other 3D rendering techniques. In VR, the contributions of each voxel (volumetric pixel) along a line of sight from the viewer's eye through the data set are summarized. This process is repeated many times to determine each pixel value in the displayed image. VR can show multiple internal and overlying features, and the displayed intensity is related to the amount of bone encountered along extending through the volume. The flexibility of the VR algorithm allows the radiologist to tailor the degree of surface shading and bony opacity to the actual clinical problem [7]. In patients suffering from congenital thoracic wall deformities, the VR reconstruction mode allows far better than all other reconstruction methods depiction not only of the osseous structures of the thoracic cage but also of the particular structures of interest for the remodeling surgeon, namely the rib cartilages and if necessary of other thoracic structures. In a patient who is referred for cross-sectional imaging, unenhanced helical 64-detector row MDCT (LightSpeed VCT, GE, Milwaukee) is performed. Typical parameters include a slice thickness of 0.625 mm, volume coverage of 40 mm/rotation with a minimum rotation-time of 0.35 s, and a weight-based low tube current technique. Using the integrated transfer rates with gigabit connectivity, the large data volume generated by routine sub-millimeter (0.625 mm) scanning is automatically transferred within a few seconds together with automatically created multiplanar reformatted images ("direct MPRs") to a 3D rendering workstation (HP Workstation xw 8000) running Advantage Windows software (Advantage Windows 4.2, GE Healthcare). The ability to directly create MPRs from the source data allows radiologists to visualize CT images online in three planes. 3D VR reconstructions are promptly managed using stored presets. After image generation, the whole data set is sent to a "Picture Archiving and Communication System" (PACS, J-Vision, TIANI, Austria).

Often, the presence of an anatomic variation will be subtle on standard axial CT images alone. This finding is particularly true of prominent convexity of the anterior rib or costal cartilage, prominent asymmetric costal cartilage, tilted sternum and its associated findings, and other rib anomalies. It may be difficult on axial images alone to show that the anomaly at the level of the palpable lump is more anterior than the ribs and the costal cartilages superior and inferior to that level. 3D reconstructions of the helical CT images are helpful to identify and to define such lesions (Fig. 5). Volume rendered images with a low threshold showing the patient's skin surface can be used to identify the protrusion palpated on physical examination (Fig. 6). By increasing the threshold and concomitantly semitransparent depiction of the skin, the underlying bone and cartilage can be demonstrated and be used to correlate the anatomic variation with the exact site of the palpable lump (Figs. 7–9). In some cases, several anatomic anomalies lead to the finding of a palpable protrusion. For example, a tilted sternum may be associated with a subluxed clavicular head or costal cartilage, or a rib anomaly can be associated with the adjacent rib protruding anteriorly and cause a palpable lesion. These combined anomalies may involve several levels of ribs or costal cartilage and are often more easily seen on 3D images. 3D images are also helpful if the palpated lesion is caused by a disease process. The relationship between the mass and the adjacent ribs can be further depicted. Transversal MDCT images together with 3D VR reconstructions can define the severity of the deformity and

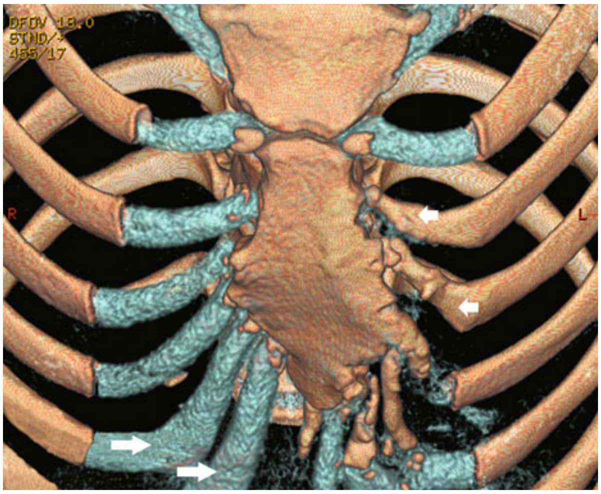

Fig. 7. Pectus excavatum in a 33-year-old woman. Oblique coronal 3D volume rendering reconstruction depicts the overgrowth of the length of the lower costal cartilages (arrows), which causes the deformity of the sternum with a sunken xyphoid. In addition the cartilages of the third to fifth ribs are missing because of complete ossification (short arrows)

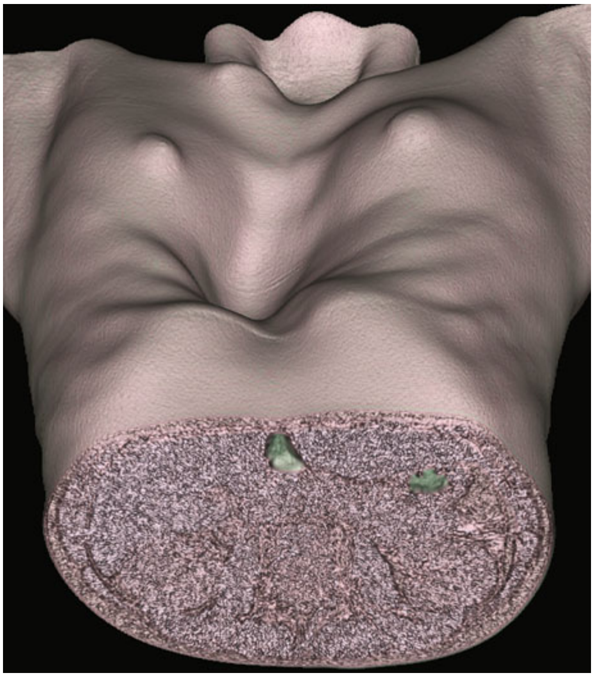

Fig. 8. Pectus excavatum in a 14-year-old girl (same patient as in Fig. 1). Oblique coronal 3D volume rendering reconstruction with a low threshold showing the patient's skin surface can be used to identify the protrusion palpated on physical examination

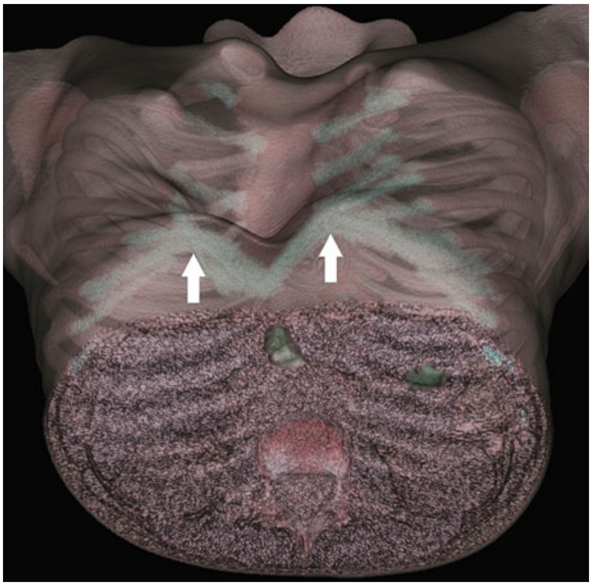

Fig. 9. Pectus excavatum in a 14-year-old girl (same patient as in Fig. 1). Oblique coronal 3D volume rendering reconstruction with a slightly increased threshold and concomitantly semitransparent depiction of the skin demonstrates the underlying bone and cartilage and can be used to correlate the anatomic variation with the exact site of the palpable lump (arrows)

identify any anomalously positioned cardiovascular structures that may complicate implantation of a pectus repair device.

Evaluation of funnel and keel chest is also possible using magnetic resonance (MR). This modality depicts sternum, ribs and cartilage, a one-stop shopping similar to CT, which includes the evaluation of all structures of the thorax, is not possible. The advantage of MR over CT and radiographs is an examination without radiation. Performance of 2D reformations in different planes is possible, 3D reconstructions like VR are not available. The image acquisition time for a chest MR (15–20 min) is much longer than a CT examination and therefore not accomplishable in one breath hold.

In conclusion, 3D reconstructed helical MDCT images assist in the evaluation of children with potential chest wall abnormalities or anatomic variation. Because of the orientation of many of these variations, the information displayed on 3D images may be helpful in identification of the anatomic variation, in communication of the presence of these benign anomalies to referring physicians, and in the development of understanding of these anomalies [8].

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3.4 Haller index, pectus-severity-index

Anton H. Schwabegger

A so-called fronto-sagittal-index and a vertebral index were described by Backer [1] already in 1961, using conventional radiographs for the measurement and assessment of preoperative situs compared with post-operative results. Hümmer in 1972 [5] described a so-called "Trichterbrust-Index" meaning a funnel chest index, calculated as a qoutient of sagittal radiographic diameters of the cranial manubrium ridge to the spinal process and the deepest depression to the spinal process. Such a similar index is described and refined nowadays, known as the Haller index, however using other techniques and measurement planes. This, in other words named pectus-severity-index (PSI), is calculated from an axial computed tomography (CT)-scan [3] or MRI [4]. It means the ratio (Fig. 1) between the largest transversal (internal) thoracic diameter and the shortest (sagittal) internal vertebro-sternal distance (*a*) at the position of the deepest inclination of the sternum (*b*) (PSI $= a/b$). In asymmetric cases, when ribs bulge inward parasternally and represent the deepest point at the thoracic wall, the internal diameter is measured from this point to a tangential horizontal line (Fig. 2) from the subjacent vertebral body [3].

A criterion of Nuss [6] lies therein, that an index with the value of 3.2 or more represents the cutoff, which defines a funnel chest deformity as moderate or severe. Values below that on the other hand yet mean no indication for invasive or mininmal invasive remodeling surgery to correct such a deformity. Daunt et al. [2] however estimates the value of 2.7 or higher, which determines a necessity of surgical treatment of the pectus excavatum deformity.

Moreover, the Haller index is dependent on age and sex of the patients and shows large variability in relation to the entire body anatomy [2, 7]. Furthermore, the anatomy of the thorax concerning its depth and width changes significantly with growth from childhood over puberty to adolescence and therefore represents a dynamic parameter. Especially during puberty, growth spurts lead to altered anatomic measures, at a time, in which, at least in our collection of patients, predominantly seek for and desire correction of that annoying stigma. Therefore within that time-frame only limited usefulness exists to apply the Haller index as a means for selection of an indication for or against any surgical intevention.

In any case, the index can serve as an additional decision-making aid to clinical diagnostics, when

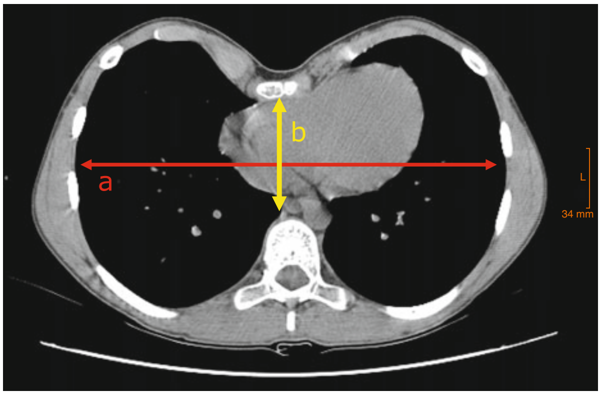

Fig. 1. Haller index in a symmetric case. *a* means the maximal horizontal exact transversal diameter and *b* is the minimal sagittal diameter, measured from the sternum to the subjacent vertebral body

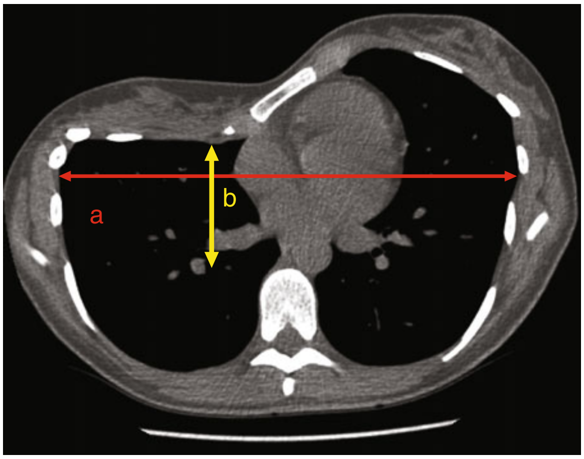

Fig. 2. In asymmetric cases *a* is measured as depicted in Fig. 1, wheras *b* is measured from the deepest point of deformity to a horizontal tangential line from the adjacent vertebral body

Fig. 3. "Dextrocardia" in a female patient with Noonan syndrome and moderate funnel chest deformity. Shifting of the heart and greater vessels to the right side, eventually due to the depression of the sternum

other investigations such as ergometry, spirometry, and psychologic diagnostics allow no conclusive decision for or against a surgical intervention. CT is helpful only in these patients, in whom thoracoplasty is required for expansion of the thoracic cage. The radiologic investigation is necessary in the more severe cases of deformity anyway, to depict the relationship of the intrathoracal organs to the skeletal structures exactly. A major depression of the sternum causes a shifting of the organs, usually further to the left, but can also lead to transposition to the right side, for example in situs inversus (dextrocardia) (Fig. 3). Particularly in cases with additional deformities at the trunk or in syndromal cases, CT figures are definitely necessary for an exact operation plan anyway to avoid injuries of intrathoracal structures when anatomical variations might be present.

The advantages of CT slices lie herein that plains of special interest can be read to determine the PSI very exactly and to exclude endangering anatomic variations. The disadvantages on the other hand remain therein that for postoperative follow-up inspections, further CT investigations were necessary, with the problematic nature of organizational expense and emerging costs of health care as well as the additional burden of radiation.

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3.5 Cardiopulmonal investigation

Barbara Semenitz

In patients with marked funnel chest deformity frequently impairment of fitness exists that can be objectified by means of a symptom-limited ergometry [8–10]. The most frequent causes for the fitness impairment are the thoracic wall deformity itself or a training deficiency and/or the combination of both. Moreover, citations are found in the literature that in 3% of patients with funnel chest deformity also a congenital cardial vitium coexists. The extent of fitness restriction in these particular cases with a cardial vitium has to be investigated in an individual and more distinct process apart from the standard measurements for the collection of patients with funnel chest deformity [3]. However, training deficiency is often also the consequence of a motivation problem because many of these patients perceive their thoracic deformity as a massive physical deficit and above all for psychologic reasons avoid participating in almost all kinds of sporting activities.

The functional restriction of fitness through the thoracic wall deformity explains itself by the reduction of distance between the sternum and the vertebral column and hence negative hemodynamic effects follow [1, 2, 4]. During physical exercise and increasing breathing movements of the thoracic cage, a sunken sternum is not capable of following the respiratory thoracic wall excursions and thus adversely restricts inflation of the lungs and ensuing cardiac output. During forced inspiration and contraction of the diaphragm, even retraction of the sternum and ensuing paradoxical breathing may be caused [6]. At the same time, based on the distortion of the heart, an impairment of the venous backflow from the Vena cava inferior into the right atrium and ventricle occurs. This again decreases the heart minute volume and therewith the capability of adaptation of the cardiac output with increasing physical exercise [10]. This impairment is observed frequently, and the distance between sternum and vertebral column is lesser than 10 cm. Below a distance of 8 cm, this restriction of cardiac output power is almost always present [10].

A further mechanical problem results from the increased strenuous effort, which is necessary to lift the sternum and to create therewith the prerequisite for cardiopulmonal adaptation to an increased demand of respiration during physical exercise [6, 11]. From this viewpoint, a measurement scale for the extent of functional impairment in a funnel chest deformity is available with the pectus-severity-index [5, 7]. The pectus-severity-index (Chapter 3.4) is calculated from an axial CT scan. It is the ratio between the largest transversal (internal) thoracic diameter and the shortest (sagittal) vertebro-sternal distance (a) at the position of the deepest inclination of the sternum (b) (PSI $= a/b$).

Also the position of the torso during investigation (ergometry) very substantially influences these sketched mechanisms of fitness alterations. In the case of a healthy patient, sufficient compensation mechanisms exist to largely equalize the efficiency in the lying (horizontal) and the sitting position during ergometric stress. However even in these healthy probationers in the lying position, the performance always is lesser, but rather modestly [3, 10]. In patients with a funnel chest deformity on the other hand, negative effects on hemodynamics are clearly more marked in the sitting than in the lying position. Ensuing from that and as Liese and Bühlmann [10] report, the heartbeat volume during the sitting examination is 20% lower than in the lying position of examination in patients with a marked funnel chest deformity.

In their investigations Liese and Bühlmann were able to differentiate between training deficiency and fitness impairment through the funnel chest deformity utilizing a submaximal performance test. At a heart frequency of 170/min either the effective working capacity (EWC) or the physical working capacity (PWC) 170 is determined by means of a stepwise increasing test on the bicycle-ergometer, first sitting, and subsequently in a lying position [10].

The comparison of the nominal output to be expected in Watt, which represents a submaximal stress, with the actual wattage permits the judgment of the effective

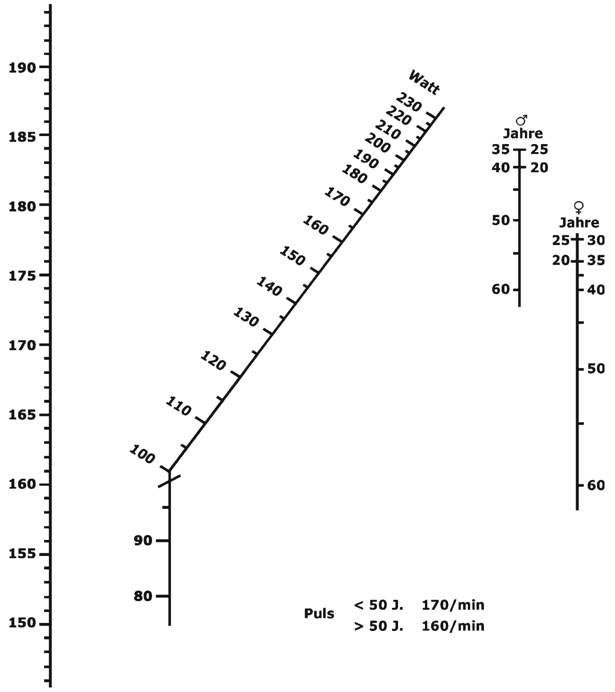


Fig. 1. Nomogram

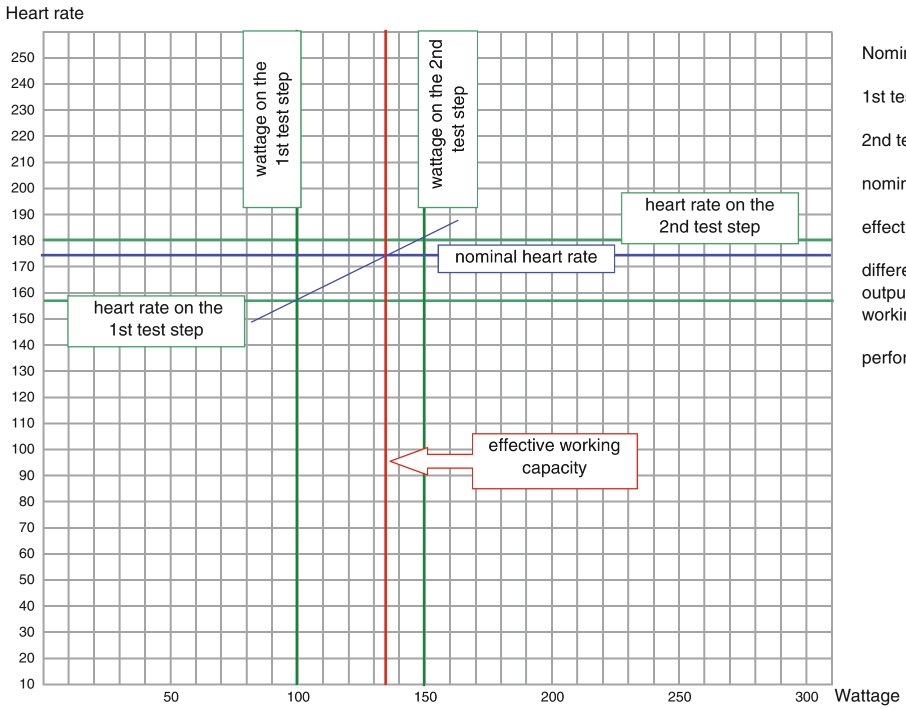
Table 1: Age-dependent calculated heart rate

Age	Heart rate	Age	Heart rate
15	187	45	161
16	186	46	161
17	185	47	160
18	185	48	159
19	184	49	158
20	183	50	157
21	182	51	156
22	181	52	155
23	180	53	155
24	179	54	154
25	179	55	153
26	178	56	152
27	177	57	151
28	176	58	150
29	175	59	149
30	174	60	149
31	173	61	148
32	173	62	147
33	172	63	146
34	171	64	145
35	170	65	144
36	169	66	143
37	168	67	142
38	167	68	142
39	167	69	141
40	166	70	140
41	165	71	139
42	164	72	138
43	163	73	137
44	162	74	136

work capacity. The nominal output is dependent on age, height, and gender. Subsequently the nominal heart beat rate according to the formula: $170 - 0.86 \times (\text{age in years} - 35)$ is calculated or taken out from a corresponding table (Fig. 1).

The physical stress is carried out as a two-step test, whereby the load of the first step should remain 25 W below the nominal wattage and that of the second step 25 W above the nominal wattage, so that the difference of the steps counts 50 W. The duration of stress per step lasts five, but at least 3 min [10]. Our practical experiences however showed that nominal wattage calculated or derived from Table 1 very often already exceeds the actual maximal performance. Therefore a determination of maximal performance by means of bicycle-ergometry of each individual patient prior to a submaximal standardized test seems to be ideal, to enable determination of the individual wattage for the submaximal stress test then. The maximal and the submaximal stress tests in the sitting and lying position would have to take place however at different days to exclude an influence of the result of the two-step tests through the maximal stress test. This procedure in many cases, however, is hardly feasible for organizational reasons like distant residency of the patients. We therefore include the case history into an estimation of the physical efficiency of the patient and correspondingly adapt the calculated wattage. For the case that the levels of the two-step test in the sitting position were selected to high and the test therefore is interrupted by the patient before a time limit of 6 min, a repetition of the test with decreased stress levels is required after a recess of at least 2 h, which extends the total test duration correspondingly.

Between that two-step test in the sitting and then in the lying position, a break should be kept for also at least 2 h. During the stress tests itself, heart rate and blood pressure are measured in 1-min intervals. The maximal heart rates of the first and the second test steps as well as



Nominal output expected	228	wattage
1st test step	100	wattage
2nd test step	150	wattage
nominal heart rate	174	wattage
effective working capacity	135	wattage
difference between nominal output expected and effective working capacity	93	wattage
performance	59%	

Fig. 2. Effective work capacity (exemplarily)

the corresponding wattages are recorded in a coordinate system (heart rate and watt), subsequently the points of measurements are interconnected. The effective work capacity then results from the determination of the wattage at the nominal heart rate (Fig. 2 exemplarily). Alternatively to this method, the determination of the PWC 170 is available.

Likewise to the method described above, testing is carried out in two steps also. However, the wattage in the PWC 170 is determined at a heart rate of 170/min. The nominal (standard) values for the PWC 170 in watt is calculated as follows: for men: kg of body weight × 3, for women: kg of body weight × 2.5.

If the investigations show that the effective work capacity and/or the PWC 170 in the sitting position is/are higher than in the lying position, a high probability is present that no hemodynamic impairment exists based on the funnel chest deformity.

Does it on the other hand turn out that the measured values of cardiopulmonal capacity in the lying position are equal to or higher than in the sitting position, then a functional impairment through the sternal depression is ascertained. The explanation for that effect is, that in the lying function the heart slips more crucially thus away from the sunken sternum, which then results is better hemodynamics and elevated work capacity. This means that corrective thoracoplasty with elevation and stabilizing of the sternum and parasternal ribs will lead to an improvement of hemodynamics and therewith efficiency or fitness.

Despite normal physical efficiency in the sitting position, an impairment of the hemodynamics in the lying position may not be excluded, and that is why we recommend that two-step test both in the sitting and in the lying position. The point of origin of that differentiation in the sitting and then in the lying position is that at that time Bühlmann and Liese recommended the procedure only with patients, whose efficiency was below average. However, actually there exist patients with funnel chest deformity who show a normal physical efficiency in an achievement test, but better in the lying than in the sitting position. If relying only on absolute values of efficiency, patients with hemodynamic impairment cannot be detected by that simple but not comparative investigation.

3.5.1 Conclusion

Differential ergometry testing should always be added to and included into the preoperative judgment of every case of patients with moderate to severe funnel chest deformity. It represents an objectifying measurement of subjectively reported impaired fitness, caused by the deformity. It helps to separate those cases with merely lack of physical training from those with true cardiopulmonal functional deficits. This differential diagnosis and distinguishing between physically based from psychologically triggered impairment of fitness evidently influences the selection of more or less invasive treatment, whether as an aesthetic indication or for functional reasons. In some cases despite apparent funnel depression measured normal fitness and without any signs of hemodynamic impairment may even substantiate the decision not to go for surgery but to suggest physical training, without or with psychotherapeutic support.

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3.6 Psychological investigation

Gerhard Rumpold, Martin Lair

A beautiful body according to the entertainment media in our society guarantees success in all areas of life, because physical attraction is often equated with positive social and intrinsic individual values. On the one hand the abstract term of beauty is predetermined socially, however, on the other hand it is also an intraindividual complex emotional and cognitive process. The subjective body perception shows a multidimensional construct which is determined from affective, cognitive and behavioral aspects. Hence, it may be seen not only as a result of the discrepancy between the ideal and real body perception [3], but it is an essential component of the self-conception and therefore, amongst others, can have far-reaching consequences on the quality of life [5]. Many investigations confirm the assumption that the satisfaction with the own body correlates significantly positively with the self-worth. Thereby, women show a higher correlation than men [12]. Particularly with youngsters a clear connection between body satisfaction and self-esteem can be allocated empirically [7, 18]. Verkuyten [19] could show that in youngsters this correlation is more significant than the connection between the self-esteem and other dimensions of the self-perception, like abilities at school or perceived popularity. The body satisfaction that comes along with self-worth also increases the positive expression of other attributes. In an investigation of students it could be shown that the more content they were with their physical appearance, the more attractive, beautiful, efficient and robust, but less worried and stressed when they judged their body, all the more they accepted it and experienced it as integrated in their self-experience [13]. According to Berscheid et al. [1] persons with above-average body satisfaction describe themselves as more charming, assertive, conscientious and intelligent than test persons with subnormal body satisfaction. In contrast to the impacts of a positive body perception, timidity, unsteadiness, depression, hostility and neurotizismus are significantly associated with body displeasedness [9].

3.6.1 Psychosocial effects of a funnel or keel breast deformity

Patients with a funnel or keel breast deformity often report about feelings of embarrassment and sense of shame based on their constitutional “flaw”. Parents mostly observe the suffering of their child and subsequently consult medical attendance. Schwabegger et al. [15] report that the degree of suffering in patients with a very distinctive keel breast deformity often is higher than with a funnel breast deformity, because the keel deformity can poorly be concealed by clothes. Researches yielded that in patients with funnel and keel breast deformity and because of this constitutional appearance, the sense of shame can lead to limited self-worth, feeling of inferiority, depressive mood, coyness, social timidity and maladaptive social behavior [14]. In their investigation Einsiedel and Clausner [6] ascertained the following, to some extent very interfering reaction tendencies: anxiety, shame, constraints, failure focusing, stigmatization feelings, enhanced suggestibility, ambivalent behavior, dissimulation and rationalization trends, limited communication ability, inhibition of autonomous trends, unspecific social problems, nervous restlessness, latent aggressiveness and limited performance. Moreover, in these patients they observed a high focusing of attention to their body, a negative appraisal of their appearance, a disturbed perception of their body shape and occasional depressive reactions. All these psychological symptoms were stronger developed in older patients (>11 years) than in younger ones. Einsiedel and coworkers led back this observation on the increasing socialization and ability to self-reflection in the course of growing-up. Therefore the features of the deformity are not authoritatively determining the individual coping with the disease, but the available psychosocial protective attributes or the individual risk factors.

A qualitative investigation with a standardized interview [4] rendered indicators for psychological disturbances on the basis of harassment through the social environment. As a result this often leads to avoidance behavior and social retreat, which then leads to interference of the quality of life. Publications uniformly report about a positive influence of the surgical correction of the deformity on the quality of life of these patients. In general they estimated themselves more happily after surgery, felt less tired and the contact with the other gender was facilitated [17]. In the explorative investigation of Roberts et al. [14] the improvement of the quality of life appeared in the subset aspects “satisfaction”, “physical and psychological sense of well-being”, “social integration” and “self-confidence”. Krasopoulos et al. [11] could substantiate that after corrective surgery the quality of life of the patients clearly improved and the self-esteem rose significantly. This was seen in increasing participation in social activities, in rising self-confidence and in the arrangement of social relations. This again led to an increase of self-confidence of the body, the subjectively perceived acceptance of the body through others, the satisfaction with the whole physical appearance and shape (not only the thorax region), the subjective health experience as well as the physical efficiency.

These carried out psychological studies show that a funnel or keel breast deformity can substantially lead to psychological disturbances. Thus Einsiedel and Clausner [6] propagate for *all* patients – irrespectively of the medical severity of the deformity – an *additional supportive psychotherapeutic support*. In their investigations they found out namely that after surgical correction but without therapeutic aid neurotic and inadequate coping strategies increase with rising age.

3.6.2 Psychological test diagnostics

According to Suita et al. [17], in most cases aesthetic-psychological reasons indicate the decision for surgery; however, according to the state of knowledge no comprehensible psychological indication criteria exist so far. Due to the results of available publications it is indeed helpful to measure the following psychosocial dimensions in the patients by psychological questionnaires and interviews.

- Psychological symptoms.
- Quality of life.
- Self-worth and self-confidence.
- Social behavior.
- Body experience.

Numerous sufficiently valid and reliable questionnaires are available in different languages for the acquisition of these dimensions; however, a listing and description of all available instruments would go beyond the scope of this contribution.

Exemplarily and to clarify the extent of a survey, at this point we would like to describe, hence, the psychological diagnostics in the Department for Medical Psychology at the Innsbruck Medical University.

With the patients and as a matter of routine in the phase of the medical preclarification, a detailed bio-psycho-social anamnesis is collected to attain a clear view in respect of the biographical effects of the funnel or keel breast deformity. Potential diagnoses resulting from this interrogation are documented according to the ICD-10 classification system. In addition, a test-psychological investigation is carried out with the following instruments.

3.6.2.1 Brief symptom inventory (BSI)

The “Brief Symptom Inventory” (BSI) [8], which represents a short form of the Symptom-Check List SCL-90-R, collects the subjectively felt psychological burden during the last 7 days. This self-judgment inventory encloses 53 questions (items) which are to be answered on a 5-stage Likert scale from “not at all” (0) to “very strongly” (4). With the BSI nine symptom dimensions and three global identity values can be calculated (somatization, obsessiveness, unsteadyness in social contacts, depression, timidity, aggressiveness/hostility, phobic anxiety, paranoid thinking, and psychotizism). Three global characteristic values (Global Severity index (GSI), Positive Symptom Distress Index (PSDI) and Positive Symptom Totally (PST)) offer a survey over the psychological burden, because they embrace all 53 Items. The GSI measures the basic psychological load, the PSDI measures the intensity of answers in which burden is existent. To fill in the BSI forms it usually takes 8–10 min. The internal consistency (Cronbach’s α) of the single scales lies between $r = 0.39$ and 0.92 and retest reliability reaches from $r = 0.68$ to 0.93. The construct-validity could be proved by very high correlations between the BSI and SCL-90-R scales.

3.6.2.2 Short form 36 health survey (SF-36)

The SF-36 health questionnaires [2] cover the subjective health independently of the state of health from the viewpoint of the affected persons. The subjective health or health-related quality of life is a multidimensional construct, which encloses the physical constitution, social relations, the functional competence and the psychological condition of the interviewees. The questionnaire is suitable for healthy ones as well as for diseased people (somatic and psychological) above the age of 14. There also exists an interview form of the questionnaire, a version for the extrinsic judgment and a short form (SF-12). SF-36 consists of 36 Items which capture 8 dimensions of the subjective health ("physical effectiveness", "physical role function", "physical pains", "general health perception", "vitality", "social effectiveness", "emotional role function", and "psychological well-being"). With the aid of 8 SF-36 subscales it is possible to measure the physical and psychological health of the patient at a higher abstraction level (physical and psychological sum-scale). The answer categories of the items vary from easy binary ("yes–no") up to 6-stage answer scales, average treatment duration amounts 10 min. The internal consistency (Cronbach's α) of the subscales lies between 0.57 and 0.94. The convergent and discriminant validity as well as the sensitivity of the procedure was checked in several investigations successfully.

3.6.2.3 Inventory of interpersonal problems (IIP C)

The "inventory of interpersonal problems" [10] detects the self-assessment of interpersonal problems in interaction with other people. The questionnaire was developed on the basis of interpersonal personality models to enable collection of subjectively felt problems in these interactions. The IIP is applicable for psychologically and physically affected as well as for healthy adults, available as a long form with 127 and an abridged form with 64 Items (IIP C). The realization of the long version claims approximately 15–20 min, of the short version 10–15 min. The answering is carried out on a 5-stage Likert-scale from "not" (0), "a little" (1), "average" (2), "fair" (3) to "very much" (4). Using the 5-stage Likert-scale, 8 scales are measured ("autocratic/dominant", "quarrelsome/competing", "unfriendly/coldly", "introverted/socially withdrawing", "unconfident/submissive", "usable/compliant", "provident/friendly" and "expressive/intrusive"). Measured internal consistency (around 0.50) and retest-reliabilities (0.81–0.90) of the inventory are estimated as sufficient. A sufficient validity in a series of studies, in which the IIP differentiated unambiguously between different clinical diagnosis groups, turned out to be satisfying.

3.6.2.4 Questionnaire for the judgment of own body (FBeK)

The "questionnaires for the judgment of the own body" [16] serves for the ascertainment of the subjective body pattern and body perception. A total of 59 Items are in the first person formulated as a statement and can be answered with "is right" or "is not right". From that four factors can be determined:
"Attraction/self-confidence" (describes the satisfaction with own body and the joy in the own body), "accentuation of the physical appearance" (describes the special stress of the appearance and the joy in the employment with the own body), "insecurity/concern" (describes a rather hypochondric burden of the own body) and "bodily sexual disrelish" (describes sexual discontent or malsensations). The answers to the questionnaire usually last about 10 min, it was primarily developed for adults; however, it can be used in youngsters too. Although this body questionnaire was primarily conceived for psychosomatic research, it has proved itself of value particularly in the clinical-psychotherapeutic area. The internal consistency (Cronbach's α) lies between 0.69 and 0.85 and the Split Half coefficients (to Spearman-Brown and Guttman) between 0.70 and 0.82. Convergent and differential validity of the questionnaire could be proved in numerous studies.
The comprising data from the anamnesis and the test diagnostics result in a comprehensive view with respect to the biography and the determinant psychosocial effects.

3.6.3 Conclusion

In the sense of an interdisciplinary approach and on the basis of the present scientific publications with results regarding the psychosocial effects, a psychological screening should routinely be carried out in all patients with thoracic wall deformities. The synopsis of the data then provides sufficient information about the degree of the psychosocial impairment and the degree of expectations concerning the surgical intervention. The anticipation of the patient about a positive result following surgery with an essential improvement of the quality of life usually is very high. Thereby it must be emphasized that an exclusive operation cannot master these expectations of the patients, as long as serious psychosocial impairments exist or restrictions during a very long period were present. The deficits experienced, possibly lasting for many years, thus correlating to permanently trained experience, naturally left behind traces in the corresponding neural areas in the sense of the theory of the neural plasticity. These cognitive and neural representations must of course be restructured, that is substitution with other experiences. This is the reason why in some patients additional psychotherapeutic aid is also required. As a result of all these conditions the team of therapists has the task to provide the patient with realistic estimations regarding the anticipated physical and psychosocial changes.

The challenge of the future will be to generate concrete cut-off values out of the test-psychological investigation to identify highly stressed patients, who can profit from the operation but with subsequent additional psychotherapy within the psychosocial environment.

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