Minimally Invasive Repair of Pectus Excavatum

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Chapter 1

Introduction and outline of the thesis

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Epidemiology

Anterior chest wall deformities are present in approximately 90% of all congenital chest defects. They arise in 0.01-0.1% of the total human population, equivalent to 6 to 12 cases per 1000 persons world wide [1,2]. Pectus excavatum (PE) is the most frequently found deformity with a male to female prevalence of 2:1 (Fig 1).

Figure 1. Pectus excavatum
With permission of subject.

PE is also seen in animals like cats, dogs and otters. The latter are thought to develop the condition by cracking open shellfish on their chests while floating in the sea [3,4,5].

For pectus excavatum there is no direct racial predisposition found. Although PE is more frequently seen in Caucasian descent than among Latinos, Africans or Asians [6,7]. In up to 45% of patients genetic determinants play a role. Family tree analysis has shown that inheritance has been autosomal dominant, autosomal recessive, X-linked, and multifactorial in different families [8,9]. The involved gene is located on the long arm of chromosome 18 [10].

The morphology of the pectus excavatum can be different from case to case. A symmetrical deformity, with depression of a part of the sternum and the adjoining costal cartilages occurs most frequently. However there can also be an asymmetrical form, a light depression of the whole anterior chest wall, or a combination deformity [11].

The survival of PE patients was investigated in an autopsy study over a 112 year period. Of the 50.496 cases there were 62 with PE. Those PE patients had a different survival period than the control groups. PE patients showed an earlier death (P< 0.001). However, older PE patients above the age of 56, survived longer than controls (P< 0.001) [12].

History

The first image of pectus excavatum comes from the Old Kingdom of Egypt, the fifth dynasty, which dates back to 2400 BC, when reliefs were made of humans. On one of these reliefs (Fig. 2) a man with probably a pectus excavatum deformity is shown [13].

Figure 2.

In Europe, the oldest findings were the preserved thoracic skeletons of pectus excavatum among a set of 48 skeletons found in Hungary in graves dated between the 10th and 16th centuries [14].

Painters like Leonardo da Vinci (1452-1519) and Jusepe De Ribera (1591-1652), draw and painted individuals with a pectus excavatum (Fig.3).

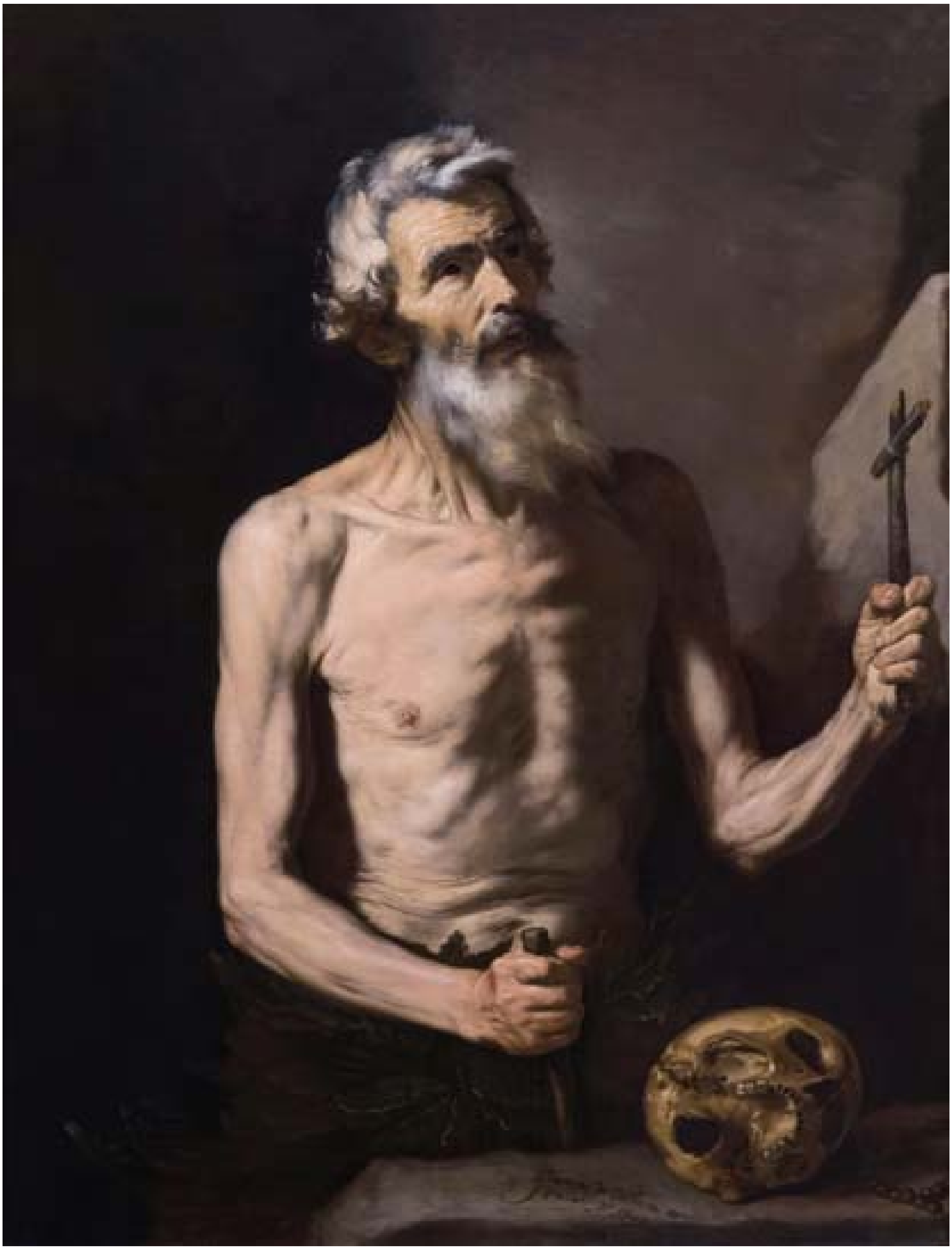

Figure 3.
Saint Onophrius (1642) by Jusepe De Ribera, with permission from the Museum of Fine Arts, Boston, Massachusetts, USA.

The first written mentioning of pectus excavatum was in 1594 by the J. Bauhin. He described a case of a patient with dyspnea and paroxysmal cough. Together with J. Schenck, Bauhins findings were published [15].

In 1820, W. Coulson, described three brothers with PE [16], C. Williams wrote in 1872 about a 17-year-old patient with pectus excavatum, whose father and brother also had a PE [17]. However, the first to describe pectus excavatum as a disease/medical condition was Eggel in 1870 [18]. Early therapy was described by W. Ebstein in 1882, he recommended breathing exercises, fresh air, lying in the lateral position, and aerobic activities [19].

Embryological development of the sternum

The sternum can be divided into three sections: the manubrium, mesosternum (sternal body) and xiphoid process. Development of the mesosternum commences during the sixth gestational week with the formation of a pair of mesenchymal bands. During the sixth to ninth gestational week, a set of sternal bars is formed as they come into contact with the growing ribs. The bars fuse with each other in the midline starting at the manubrium sterni (in a cranio-caudal direction) and chondrify, forming a single solid cartilaginous rod by week ten.

The caudal extension of the sternal bars, gives rise to the xiphoid process. Once fusion and chondrification of the sternal bars are complete, the segmentation of the sternal body into sternebrae becomes visible as ossification centers start to develop. This segmentation occurs under the influence of the ribs and their attachment sites to the mesosternum. The manubrium develops independent of the sternal body.

Ossification of the sternum begins around the fifth gestational month. Ossification of the xiphoid process only commences after the age of three years and is extremely variable. Complete incorporation of all the various sternebrae into the sternal body can be expected in individuals older than 15 years (fig 3) [20,21,22,23].

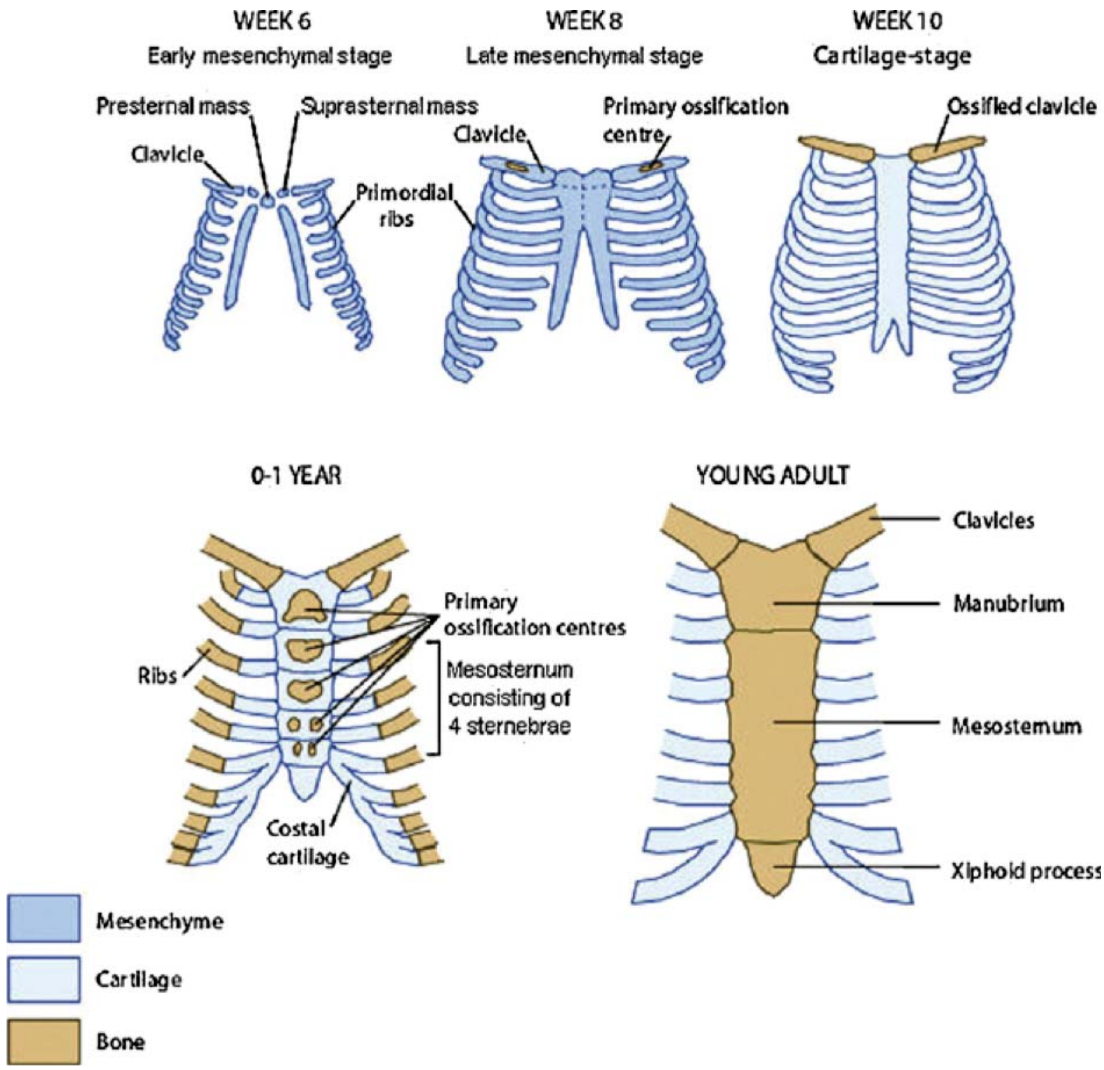

Figure 4. Embryological development sternum in stages.
By van der Merwe A et al. A review of the embryological development and associated developmental abnormalities of the sternum in the light of a rare palaeopathological case of sternal cleftin. Homo 2013; 64: 10.1016/j.jchb.2013.01.003.

The sternum eventually articulates with seven costal cartilages and with the clavicles. Synovial joints articulate the costal cartilages to the sternum. The radiate costo-sternal ligaments secure the costal cartilages to the sternum. The xiphoid gives attachment to the linea alba and the most medial fibers of the rectus abdominis, and its posterior aspect gives rise to some of the fibers of the diaphragm [24].

PE is a deformity of usually the lower sternum and the adjacent costal cartilages. The exact embryologic basis for this sternal abnormalities is not clear. However, abnormalities of rib morphogenesis and growth are the most likely causes [25,26]. Intrinsic abnormality of the costochondral cartilage is suggested by the occurrence of PE in patients with connective tissue disorders, such as Marfan syndrome (5-8%) or Ehlers–Danlos syndrome(3%) [27].

Surgery

The first surgical correction of the pectus excavatum was undertaken in 1911 by L. Meyer. He removed the patient's second and third ribs [28]. Surgery was also conducted by Ferdinand Sauerbruch in 1913 [29]. His patient suffered from severe dyspnea at rest and dysrhythmia [16]. Later the technique was changed to bilateral costal cartilage resection and sternal osteotomy with external traction for 6 weeks, see figure 5 [30].

Figure 5. External chest wall traction

In 1925 Zahradnicek treated the PE of a 16-year-old boy, whereby he used two metal wires introduced through the sternum to maintain traction [31].

In 1939, A. Ochsner and M. DeBakey published a review of the various operative techniques of that time [32]. The high mortality (6 of the 25 patients died and few showed improvement as a result of the operation) led them to advocate less invasive operations. In 1939, L. Brown suggested surgery limited to the removal of the ligaments joining the sternum with the diaphragm [33]. In 1949, M. Ravitch proposed sternal mobilization involving the transection of all sternal attachments, including the intercostal neurovascular bundle, rectus abdominis muscle, and attachments of the diaphragm, as well as the excision of the xiphoid process. The shortened costal cartilages were reattached to the correctly positioned sternum with non-absorbable sutures [34].

More techniques related to this surgery with small modifications were described in 1953 by C. Lester, E. Chin and H. Brodkin in 1958 [35]. In 1963, F. Robiscek described a method involving subperiosteal excision of cartilages, transverse displacement of the sternum, and excision of the forward-displaced lower segment of the sternum. The rectus abdominis muscle and the xiphoid process were then sutured to the newly formed lower part of the sternum. In cases of asymmetrical deformities, he used bilateral cartilage resection and double osteotomy of the sternum [36].

In 1953 R. Gross published a textbook entitled "The Surgery of Infancy and Childhood". He reported good results of corrective surgery involving cartilage resection in two locations: in the vicinity of the rib attachment and near the sternal attachment, followed by sternal osteotomy [37]. In 1958, K. Welch, demonstrated very good results of surgery conducted in 75 patients without the need for transecting the intercostal bundles or the rectus abdominis muscle [38]. In 1954, J. Judet and later Wade in 1970, completely rotated the sternum and fixed it with its dorsal part facing upward [39,40].

Corrective pectus excavatum surgery without the use of external traction was characterized by high recurrence rates. Subsequent operative modifications were taken with as result the internal stabilization of the sternum. R. Dorner in 1950 used homologous ribs, whereas G. Wallgren, in 1956 and M. Sulamaa employed a curved metal bar passed through the lower end of the sternum, which supported the sternum from both sides, keeping it on the ribs [41]. A similar technique was used 5 years later by P. Adkins and B. Blades, whereby the bar was passed behind the sternum [42]. Same solutions were mentioned by K. Welch in 1958 [38] and by A. Haller [43].

Other materials for providing support to the sternum included Dacron vascular graft struts [44], small titanium struts [45], seagull wing self-retaining prostheses [46], substernal mesh bands [47], or used the bio-absorbable weave technique [48]. Also silicone implants were used for correction [49].

The surgical technique proposed by M. Ravitch, modified by many, became the most used treatment method for chest wall deformities (Fig.6). One drawback was, that costal cartilages resection could lead to bone or rigid scar tissue formation, which in turn could lead to restrictive limitations of the chest wall (Jeune syndrome) [50,51,52]. This gave rise to surgeons not performing the procedure in small children, but waiting till after puberty for surgery [53]. The recurrence rate for classical surgery was between 2 and 20.5%, according to various authors [54].

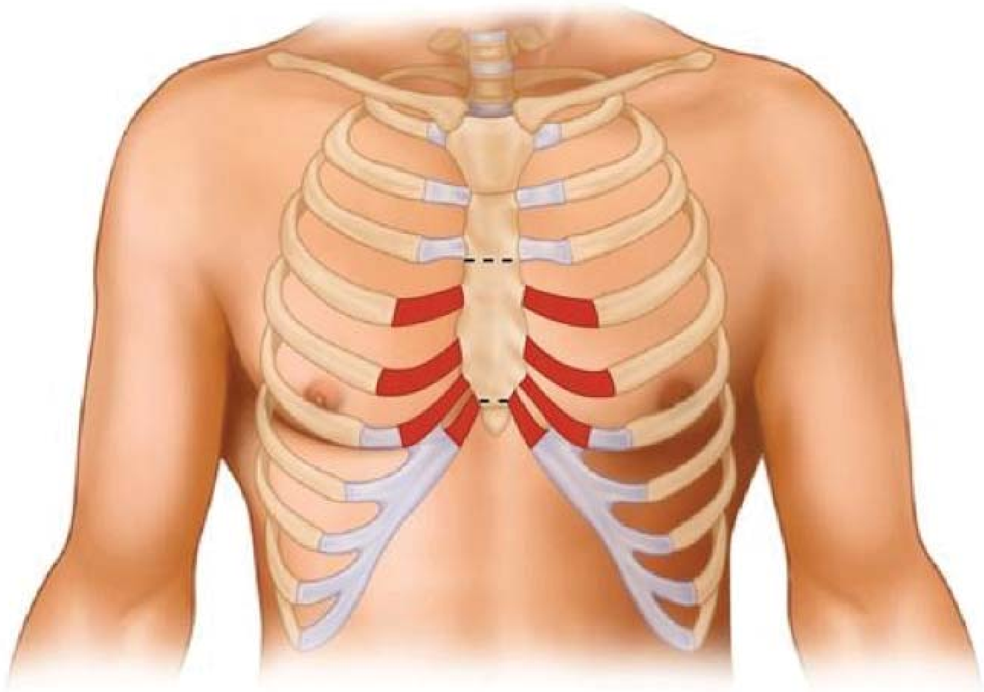

Figure 6. Schematic view of pectus excavatum repair as performed by Ravitch
The dotted lines show the lines of the osteotomy and in red are the costal cartilages which are shortened and reattached to the corrected sternum. Reprint with permission Springer Nature.

In 1998, D. Nuss reported his 10-year experience with treating pectus excavatum by the substernal introduction of an internal corrective bar without the need for costal cartilage resection and sternal osteotomy [55]. Over time, many modifications have been made to the method, for example adding of stabilizers, thoracoscopic assisted, rib wire etc. [56].

Next to the surgical correction more non-invasive methods for treating PE have been developed, as sternal traction with two magnets, or vacuum pump use [57,58]. Also braces and exercise programs have been used.

Still, surgical treatment remains the only proven effective method for treating deeper chest wall deformities [56].

Aim and design of the study

Aim

Pectus excavatum (PE) is a posterior intrusion of the chest wall into the thoracic cavity. The majority of patients with a pectus excavatum seek medical advice during adolescence. This period in their life is also a transition period with physical, chemical, hormonal and social changes. Although the physiologic and psychologic consequences vary, for a growing number of patients the lesion seems to be troublesome enough to consider corrective surgery.

The surgical procedures that are offered to this group of patients consists mainly of two different techniques for correction of the pectus excavatum. The modified Ravitch and the minimal invasive repair of the pectus excavatum (MIRPE) technique. Studies about the procedures have mainly focused on the (per)-operative technical issues and peri-operative management. Most studies are based on retrospective case series and improvement after surgery is generally measured by changes in health related quality of life (HRQoL) or surgical parameters.

Unfortunately, little is known about the middle term and long term effects of especially the MIRPE technique (and more specific the Nuss technique) on quality of life, pain and functional, psychological and social capabilities. Little is known about general QoL, pain after discharge, and post-surgery sport activity development.

To investigate this area, we started a multi-center prospective longitudinal cohort study.

Design

All consecutive patients with PE who were referred to the outpatient clinic of one of the five participating centers (AMC, VUMC, UMCG, Juliana Children's Hospital/Haga-Hospital, Radboud UMC) were asked to participate in this study between December 2011 and December 2016. Patients younger than 12 years of age were not eligible for correction at our institutions and therefore did not participate. Excluded were also patients or parents with insufficient knowledge of the Dutch language. Those with associated connective tissue diseases were allowed to participate in the study.

Patients under the age of sixteen years gave informed consent as did their parents. All patients over the age of sixteen gave informed consent. The medical ethics committee approved the study.

Surgical procedure

In all study patients with PE the Nuss procedure, also referred to as MIRPE, was performed. Surgery was performed by dedicated pediatric or thoracic surgeons. The operative technical procedure was similar in all centers. Correction of the pectus excavatum defect without cartilage resection by applying outward pressure to the sternum at the point of maximal inward deflection, using a custom-contoured steel bar. The Nuss bar is placed in the pleural space, passed behind the sternum, rotated 180 degrees, then attached laterally to the outer edge of the rib cage (Fig 7)[55].

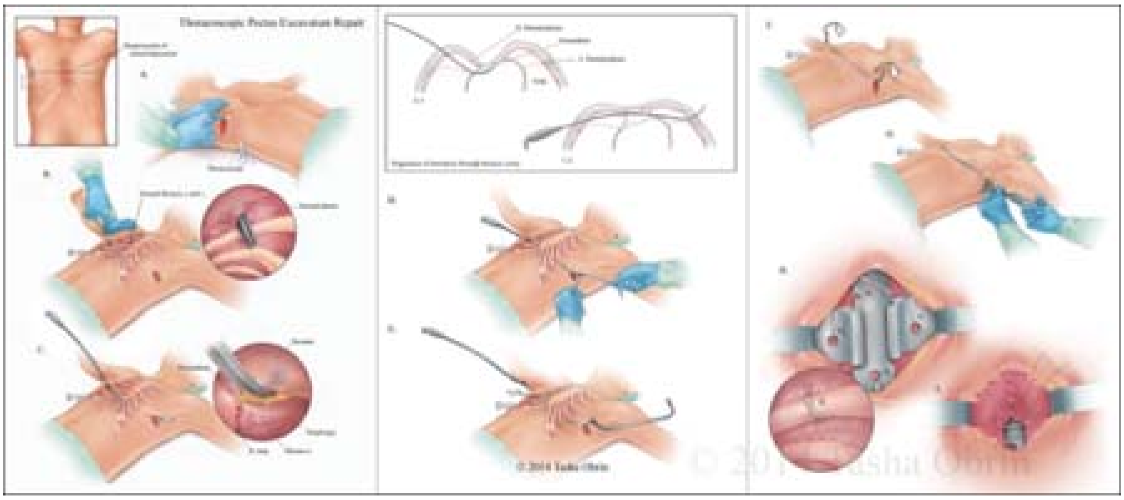

Figure 7. MIRPE procedure
Tasha Obrin 2014

Post-operative pain management was executed with patient controlled epidural analgesia or patient controlled intravenous analgesia using morphine and occasionally ketamine or only oral pain medication. When possible the patients on epidural or intravenous analgesia were changed after 3 days to oral pain medication.

Questionnaires

Patients were divided into 3 groups based upon age, being younger than 16 years, 16-18 years and older than 18 years of age. Questionnaires used differed per age group. This was necessary to meet the validation criteria for the different questionnaires which are limited to age group.

The pre-operative questionnaire was completed during the last outpatient clinic visit prior to surgery. Post-operative questionnaires were sent to the patients on the predefined follow up moments. If no direct response was received a reminder by either mail or telephone was used. Measurement moments were pre-operatively, 6 weeks, 6 months, 1 year, 2 years, 3 years and 5 years post-operative (Table 1).

Quality of life was assessed using the Dutch version of the CHQ-87 in patients younger than 16 and between 16 and 18 years of age and with the short version of the World Health Organization Quality of Life assessment instrument (WHOQOL-bref) in patients between 16 and 18 years and older than 18 years of age. This implies that some patients completed both CHQ and WHOQOL-bref at measurement moments.

The body image and psychological domain were assessed using the World Health Organization Quality Of Life Questionnaire-bref. This is the short version of the WHOQOL-100 [59]. It consists of questions assessing QoL in four domains being physical health, psychological health, social relationships, and environment and a general evaluative facet (overall quality of life and general health). For the purpose of our study a complete facet of the WHOQOL-100 has been added to the WHOQOL-bref being the facet body image. Items are scored on a four point Likert scale. Higher scores indicate a better QoL.

The Child Health Questionnaire-87 is a generic QoL assessment tool that has good reliability and validity [59]. This questionnaire covers the physical, emotional and social well-being of children between the age of 8 and 18 years. Self-esteem as well as emotional limitations and general health are domains of the CHQ-87. In the domain self-esteem one question is specific for body image perception of the patient. Items are scored using a four to six point Likert scale and converted to a 0 to 100 point continuum, with higher scores indicating a better QoL. Norm values of the Dutch population are available and allow for comparison with 'healthy' children [60].

Table 1.

age	Pre-operative	6 weeks	6 months	1 year	2 years	3 years	5 years
Below 16 years	DQ CHQ STAI-Trait STAI-State PEEQ	DQ CHQ STAI-State SSQ VAS	DQ CHQ STAI-State SSQ VAS	DQ CHQ STAI-State PEEQ SSQ VAS	DQ CHQ STAI-State PEEQ SSQ VAS	DQ CHQ STAI-State PEEQ SSQ VAS	DQ CHQ STAI-State PEEQ SSQ VAS
16 – 18 years	DQ CHQ WHO- QOL-Bref STAI-Trait STAI-State SF-36 PEEQ	DQ CHQ WHO- QOL-Bref STAI-State SSQ SF-36 VAS	DQ CHQ WHO- QOL-Bref STAI-State SSQ SF-36 VAS	DQ CHQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS	DQ CHQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS	DQ CHQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS	DQ CHQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS
Above 18 years	DQ WHO- QOL-Bref STAI-Trait STAI-State SF-36 PEEQ	DQ WHO- QOL-Bref STAI-State SSQ SF-36 VAS	DQ WHO- QOL-Bref STAI-State SSQ SF-36 VAS	DQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS	DQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS	DQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS	DQ WHO- QOL-Bref STAI-State PEEQ SSQ SF-36 VAS

DQ:Demographic Questionnaire, SSQ: Single Step Questionnaire, PEEQ: Pectus Excavatum Evaluation Questionnaire, CHQ: Child Health Questionnaire, WHOQOL-Bref: World Health Organization Quality of Life assessment instrument, VAS: Visual Analogue Score

Anxiety was assessed using the short versions of the State and Trait Anxiety Inventory [61] [62]. Trait anxiety concerns differences in individuals in the disposition to respond to stressful situations with varying levels of anxiety. State anxiety refers to the momentarily experienced feeling of apprehension and tension. Items are scored on a four point Likert scale, these scores are added up and then dichotomized in high or not-high, with cut-off scores derived from the manual. The short versions have good reliability and validity [63] .

The Pectus Excavatum Evaluation Questionnaire (PEEQ) was also used. It was developed to measure physical and psychosocial quality-of-life changes after surgical repair of pectus excavatum. It consists of nine questions asking the children how they feel or act about their bodies. The instrument has high test-retest reliability (Rho > 0.6 for all retained questions) [64].

In order to measure the satisfaction with surgery and the post-operative appearance of the thorax the Single Step Questionnaire (SSQ) was used [65]. This assessment tool uses 16 questions to assess satisfaction. Scores are added and a score above 41, with a maximum score of 84 is considered to be a satisfactory outcome. This questionnaire was only completed post-operatively. The concept of the questionnaire is that one measurement moment gives information concerning pre-operative and post-operative satisfaction.

For Health-related QoL measurements the SF-36 questionnaire was used preoperatively and after surgery. It is completed at given times after surgery (being 6 months and 1-2-3-5 years). The Short Form-36 (SF-36) Health Survey questionnaire is a 36-item self-report inventory with eight dimensions of physical and mental domain, including Physical Functioning, Role–Physical, Bodily Pain, General Health, Vitality, Social Functioning, Role–Emotional, and Mental Health [66]. The SF-36 questionnaire has been found to have a robust predictive validity for health-related outcomes [67].

Pain in rest and during activity post-operatively was measured using a 100 mm Visual Analogue Scale [68]. The VAS scores were recorded post-operatively.

A demographic questionnaire was also used at the different time interval. Questions were asked about age, sex, social habits, school and/or work, family history, and sports activities.

Outline of the thesis

This thesis contains different aspects of the treatment of patients with a pectus excavatum through the MIRPE technique, which have not been investigated before.

The first five chapters focus on the pre-operative and early post-operative period. The second part of the thesis describes the effects of MIRPE on the longer term and critical evaluation of outcome measurement and cost-effectiveness.

Chapter 2 addresses the information available on the internet with respect to PE. Although internet is an important source of information for patients, the quality of information for pectus excavatum patients was not yet structurally measured. The quality and arrangement of the websites is especially important because the majority of patients with a pectus excavatum seeking information are adolescents and have a different way of retrieving information from websites, but are also vulnerable for misconception of information.

Chapter 3 contains an overview of the surgical trends in the Netherlands with concern to the numbers/volume of pectus excavatum surgery performed in the last decades and the evaluation of the part of minimal invasive surgery in this trend.

Chapter 4 gives an answer to the question whether there is a correlation between pre-operative measurements of anxiety and post-operative pain, since pain management is such an important issue in this patient group and pain experience appears to be influenced by the level of fear of a patient and his or her psychological status.

In chapter 5, we look at pain, which is a major issue, after correction of a PE. Especially the effect of pain on the QoL of the patients. Any potential variable which can be influenced to limit pain is of great importance.

Chapter 6 concerns the early changes after surgery in patients with regard to self-esteem and QoL.

Chapter 7 contains the results of the outcome measurement “Single Step Questionnaire” (SSQ) on different moments in time after surgery. The developers of the SSQ claim that the score only needs to be determined once and does not differ over time post-operative. In this part of the study the questionnaire was applied multiple times and results are presented.

In chapter 8 we describe the changes in sport activity from pre- to post-operative. The assumption was that the correction of the PE would lead to more sport activity. This because with their “new” chest patients would feel more secure and become more engaged in sports.

Chapter 9 is about the cost-utility of the surgery after 1 year. Knowledge of cost-effectiveness of surgical procedures is still limited, especially of partial cosmetic surgery.

A general discussion on the study results and future perspectives are discussed in chapter 10.

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