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Review Article

Pectus bar removal – why, when, where and how

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ABSTRACT

Objective: Despite its less invasive nature, the widespread use of the minimally invasive repair of pectus excavatum (MIRPE) procedure has been associated with a significant number of serious complications. On the other hand, Pectus bar removal (PBR) is often considered a simple procedure and often scheduled in an outpatient setting. However, several studies report near-fatal complications not only during bar placement, but also during bar removal. The aim of our study was to clarify why a pectus bar should be removed, timing for removal, where PBR should be performed, and overall setup for safe removal.
Methods: A comprehensive review was performed in accordance with PRISMA guidelines, searching for articles published since 1998 in English. "Pectus bar removal AND (near-fatal) complications" were the applied terms. Inclusion criteria were articles reporting on the focus of PBR after MIRPE. Eligible study designs included (retrospective) case study series, case report and reviews. Full-text articles in which the technique in general was described were omitted.
Results: Recently published results of an online survey raised awareness about type and number of possible complications during PBR. Furthermore, our comprehensive literature review identified only a few, but serious complications during PBR.
Conclusions: PBR has a high safety profile but in rare cases may be associated with major complications such as life-threatening hemorrhage from various thoracic sources. This risk is higher in patients with a history of complex MIPRE. In an effort to decrease these complications we recommend bilateral opening of surgical incisions, unbending the bar and meticulous mobilization of the bar. To manage these complications if they occur, we recommend removal in a hospital setting with adequate resources and personal including cardiac surgeons. If the postoperative course is uneventful discharge on the same day is reasonable.

1. Introduction

After its introduction by D. Nuss in 1998, the minimally invasive repair of pectus excavatum (MIRPE) has gained great popularity and it is considered the "gold-standard" for surgical repair of pectus excavatum in pediatric, adolescent and even adult patients. Surgeons' experience increased and technical modifications such as routine thoracoscopy during retrosternal dissection were introduced to decrease complications during pectus repair. Several studies reporting on risks and nearby-fatal complications during MIRPE raised awareness how to avoid these complications during pectus repair [1,2]. Furthermore, sternal elevation techniques have contributed to the avoidance of complications during bar placement [3]. In contrast, pectus bar removal (PBR) is often considered a "minor" procedure, performed as a blind procedure when passing the substernal tunnel and often scheduled in an outpatient setting. The term "blind" outlines the fact that we usually are not able to visualize the tip of the pectus bar when removing it from the substernal tunnel. Recently published results of an online survey raised awareness about risk of serious complications during PBR [4].

The goal of our study was to review why a pectus bar should be removed, timing for removal, where PBR should be performed, overall setup in the OR for the procedure, and review of major complications that have been reported during PBR. We conducted a thorough literature review focusing on different techniques of PBR as well as occurrence of rare but significant complications including fatal ones. We tried to determine predisposing factors for complicated PBR, as well as technical details related to PBR that have

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been developed to reduce or possibly prevent the risk of major life threatening complications.

2. Methods

A comprehensive review was performed in accordance with PRISMA guidelines. Using MEDLINE and PubMed databases, we searched for articles published since 1998 in English. “Pectus bar removal AND (near-fatal) complications” were the applied terms. Inclusion criteria were articles reporting on the focus of PBR after MIRPE. Eligible study designs included (retrospective) case study series, case report and reviews. Full-text articles in which the technique in general was described were omitted.

3. Results

A total of 145 studies were identified. 4 studies and case reports had to be excluded since the language was Chinese (3) or Hungarian (1). Another 4 studies had to be excluded since their main focus was the role of chest radiography following PBR. The authors of 108 studies reported on their institutional experience including general aspects of diagnosis and surgical treatment of pectus excavatum and/or pectus carinatum as well as patients satisfaction. Since there was no focus on PBR and PBR related complications, these studies were omitted.

3.1. Pectus bar removal – why?

Most pediatric surgeons agree that the ideal age for MIRPE is between 14 and 16 years of age [5,6,7]. Orthopedic surgeons generally recommend removing metal implants in pediatric and adolescent patients when the fracture healing process is completed. Looking for evidenced-based data to confirm this practice we noticed that this routine practice is more based on personal experience. Reviewing the current literature, there are no evidenced-based guidelines supporting or disputing the common practice of elective implant removal after fracture healing [8,9]. At least in the pediatric population, the procedure proved to be safe performed at the upper extremity, whereas more complications were observed at distal localizations [10]. In the adult population, recommendation related to hardware removal might be age dependent. Like all metal implants, the pectus bar is a foreign body, with all well known implant related risks such as local reaction, infection, development of allergy, secondary displacement, etc.. Extremely rare but significant, pectus bar migration may cause intra-cardiac erosion [11], erosion of the internal mammary artery [12] or aorto-to-right ventricular fistula [13], or may cause severe ossification [14]. Furthermore, persistent symptoms like mild discomfort during sleep (in particular in lateral position) and/or when sneezing, laughing, etc. have been reported by some patients after MIRPE. Occasionally patients may complain about discomfort with strenuous activities.

Albeit rare but significant, advancing age, particularly in males, might be associated with an increased risk for cardiac disorders like CAD and other cardiac conditions. In case of emergent cardiac compression is needed, and/or if a median sternotomy is necessary, the presence of a pectus bar on the underside of the sternum may hinder appropriate care [15], or at least limit the ability to perform effective cardiac compression [16,17].

3.2. Pectus bar removal – when?

According to our own experience and confirmed in larger patient series [5,6,7,18–25], the pectus bar is maintained 2 to 4 years, based on the severity of the chest wall deformity and the age of the patient at the time of PBR. Nuss et al. impressively demonstrated the effects of different durations of bar placement [24]. If PBR is performed too soon (2 years or less) the recurrence rate may increase [24]. It is generally recommended that the bar should remain in place for 3 years. Keeping the bar more than 4 years or in inappropriate position may contribute to significant ossification which may increase the difficulty of PBR procedure [14,26].

Although affecting only a small number of female patients, Chang et al. raised the interesting question whether a pectus bar should be removed before or after pregnancy [27]. They reported on two adult female patients who had undergone MIRPE and successfully delivered prior to PBR. They noticed no major complications, but observed an increase of chest pain in the third trimester. Since this represents a rare constellation of patients, it is difficult to verify such occurrence during pregnancy.

3.3. Pectus bar removal – where/which environment?

After it’s introduction, several reports on risks and near fatal complications during MIRPE have helped surgeons develop technical modifications which have resulted in increased safety and a lower rate of overall complications during pectus repair. In contrast, PBR has often been considered a “minor” procedure, performed as a blind procedure without visualization of the tip of the pectus bar when removing it from the substernal tunnel, and often scheduled in an outpatient setting. Several case reports about complications and near-fatal outcome during PBR published within the last decade [Table 1] raised awareness that not only MIRPE, but also PBR may be associated with significant risks.

An online survey submitted to the Chest Wall International Group (CWIG) members was conducted to explore the type of complications during/after PBR, risk factor and preventive actions undertaken to make the procedure safer [4]. 116 experts in the field responded. 28% of the respondents had experienced some level of complication during PBR, and 12% had experienced at least one serious complication. There was no mortality reported. Major surgical interventions to treat complications include sternotomy, thoracotomy, and life-support maneuvers. Bleeding from intercostal artery (34.9%) and severe adhesions in the bar tunnel (26.9%) were the most common causes of acute intraoperative complications in this survey. Major bleeding during PBR has previously been reported by Cohen et al. [23]. Two out of 1628 patients (0.12%) with bleeding from the medial bar tract required blood transfusions due to an estimated blood loss of 2000 ml and 3000 ml. Both patients survived.

In summary, surgeons must be aware that PBR might result in serious complications. Even if it is quite rare, it is important to be prepared to manage minor and major complications. Since some bleeding events have occurred on routine cases, availability of technical equipment including a sternal saw, blood products and cardiac surgical backup must be considered. The procedure ideally should take place in the hospital setting where blood banks and multidisciplinary care is available in very short notice if needed, especially in patients who had a complicated course during pectus repair. For that reason, we recommend performing PBR in an appropriate hospital setting. If the procedure and postoperative course are uneventful, the patient may still be discharged on the same day.

3.4. Pectus bar removal – which technique and which instruments?

Several surgical techniques including special positioning of the patient for PBR have been described. Changing the body to the lateral recumbent position to remove the bar along the body surface was described by Croitoru et al. [28]. St. Peter et al. proposed a new method using two OR tables avoiding the need to straighten the bar [29,30]. Another technique avoiding unbending

Table 1
Near-fatal complications during/after pectus bar removal.

Author	Year	Complication during/after pectus repair	Complication	Repair/source of bleeding	Outcome
Leonhardt J et al. [41]	2005	Redo pectus repair after failed MIRPE 6 months before	Massive bleeding from lung injury	Sternotomy; injury of segment artery of the lower lobe	Recovery; no pectus repair
Bouchard S et al. [42]	2009	Local revision 1 month after MIRPE; pericardial effusion 2 months after MIRPE; PBR 6 months after MIRPE	Cardiac injury	Sternotomy; 2 cm hole in the ventricle	Death
Haecker FM et al. [43]	2009	Postpericardio-mytomy syndrome	Cardiac injury	Bilateral thoracotomy; 2 holes in right ventricle	Recovery
Jemielity M et al.[44].	2011	Half rotation of upper bar after 6 months	Aortic hemorrhage	Thoracotomy with cardiopulmonary bypass; bleeding from aortomediastinal fistula	Recovery
Nyboe C et al. [18]	2011	Nothing mentioned	Hematothorax due to intercostal bleeding	Thoracotomy	Recovery
Kye YK et al. [45]	2012	Nothing mentioned	Lung herniation of the right middle lobe (4y after PB removal)	Thoracotomy; Segment resection of right middle lobe	Recovery
Carluggi M et al. [39]	2013	Mild recurrence/bar flipping 30 months after MIRPE	Massive right sided hematothorax	Thoracotomy; Lobectomy middle lobe	Recovery
Sakakibara K et al. [46]	2013	Pyrexia and cough for 14 days following MIRPE	Massive bleeding from left thoracic cavity due to injury of the right ventricle	Sternotomy with cardiopulmonary bypass, open repair of a 9 cm long perforation of the right ventricle	Recovery
Notrica D et al. [47]	2014	Erosion of the upper bar into the sternum	Erosion of left internal mammary arteries (IMA)	Bilateral thoracotomy; Proximal ligation of IMA	Recovery
Zhang DK et al. [48]	2015	Nothing mentioned	Internal thoracic artery bleeding	Thoracotomy	Recovery
Park HJ et al. [20]	2016	Nothing mentioned	Internal thoracic artery bleeding	Thoracotomy with cardiopulmonary bypass	Recovery
Henry B et al. [40]	2018	Postoperative atelectasis; Factor VII deficiency	Right middle lobe laceration	Thoracotomy; Lobectomy middle lobe	Recovery
Hebra A et al. [2]	2018	Pericarditis, pericardial effusion and pneumonia needing pericardiocentesis after MIRPE	Ventricular injury and pericardial adhesions	Thoracotomy	Death
Cohen NS et al. [23]	2018	Nothing mentioned	2 patients with massive bleeding	Bleeding from an intercostal vessel Bleeding from large vein (bar tract)	Recovery
Dahlbacka SJM et al. [49]	2019	Redo MIRPE 3 months after MIRPE for secondary bar displacement; Pericardial/pleural effusion with rec. bar displacement 2 months after redo-MIRPE	Aortic hemorrhage	Sternotomy, Cardiopulmonary bypass	Recovery

of the bar was described by Chon and Shinn [31] in which the patient is placed in prone position, the patient is prepared in the Mohammedan prayer variation with the knees flexed, chest supported with two long pillows, arms abducted at the shoulder, and head slightly tilted upward. They open both lateral incisions to remove fixation sutures or wires. The substernal bar is simply grabbed with a bone hook or Kocher forceps and can be removed with even a towel clip and pulled through with the natural curvature of the bar without any bending [31].

In general, we also recommend reopening both lateral incisions used for bar placement, as described by several authors [24,32,33] and confirmed by our online survey [4]. Furthermore, unbending and straightening of the pectus bar before starting its mobilization is recommended. Ring-tip and slip-tip benders are useful instruments to unbend the bar.

In contrast, Varela et al. and Liu et al. see no need to unbend the bar before removal. They recommended reopening only one skin incision where the stabilizer was placed [34,35].

In case of severe lateral ectopic calcifications, hammer and chisel may be needed to mobilize and expose the lateral edge of the pectus bar [20,33]. To avoid severe bone formation, proper bar placement during pectus repair is important. Ostlie et al. determined that sub-muscular positioning of the pectus bar virtually always results in increased bone formation with secondary increase of blood loss during PBR [26]. They concluded that careful placement of the bar in the subcutaneous position without violating the fascia should be used to avoid such undesirable effects.

Some additional maneuvers to reduce the risk of bleeding during PBR have been reported in the literature. Besides bar alignment, the use of rubber protectors around the serrated edge of the bar to reduce the risk of accidental injury of surrounding tissue and mammary vessels was recommended by Milanez et al. [36]. Another technique described by Toselli et al. is the safety string maneuver that may be used when bleeding from the bar tract cannot be controlled by direct pressure [37]. This requires tying an umbilical tape to the end of the bar when it is removed and then tying a sponge to the umbilical tape that can be pulled back through the bar tract to tamponade any hemorrhage [37]. Some authors recommend using sternal elevation technique and/or thoracoscopy not only for pectus repair, but also for PBR [20,38–40].

3.5. Pectus bar removal – which major complications are known from the literature?

Given the total number of PBRs performed worldwide, the risk of serious complications should be considered to be quite rare. The most common complications after PBR are wound seroma and pneumothorax. This was confirmed by several studies with a large number of patients [4,5,18,20–23,25] [Table 2]. Bilgi et al. described a group of 43/246 patients (17.5%) who experienced complications during PBR or in the early postoperative period. Patients who had complications were significantly older than patients with no complications. Patients with double bars removed were significantly more likely to have perioperative complications and com-

Table 2
Most common complications during/after pectus bar removal.

Author	Patients	Wound seroma/infection	Pleural effusion	Pneumothorax	Hematoma	Hematothorax/Bleeding
Kelly RE et al. [5]	854	1 (0.11%)	N. m.	3 (0.35%)	N. m.	N. m.
Bilgi Z et al.[21].	246	29 (11.8%)	2 (0.8%)	3 (1.22%)	N. m.	3 (1.22%)
Nyboe C et al. [18]	343	N. m.	N. m.	5 (1.5%) (chest tube: 3 pt.)	N. m.	3 (0.9%) (chest tube: 2 pt.) (open surgery: 1 pt.)
Park HJ et al. [20]	1821	43 (2.36%)	3 (0.16%)	0	4 (0.22%)	3 (0.16%) (open surgery: 1 pt.)

N. m.: not mentioned.

plications requiring additional interventions. Applying minor procedures such as placement of a subcutaneous drain and/or chest tube if needed as well as immediate packing of the bar tract were successful in the management of such complications [21]. Local fibrosis, ossification and intrathoracic bar displacement were identified by Katrancioglu et al. as most common challenges during PBR [22].

Rare but significant complications including fatal ones during PBR have been described in the literature and are summarized in Table 1. Massive bleeding from intrathoracic vessels including the aorta, cardiac/ventricular injuries and lung injuries were the most common reported potential sources of severe life-threatening bleeding, managed by unilateral or bilateral thoracotomy, sternotomy and the selective use of cardiopulmonary bypass. Our review of the literature indicated that most of these patients had a previous history of major complications during or immediately after primary pectus repair such as pericarditis, pericardial and/or pleural effusion, sternal erosion of the pectus bar and bar displacement [Table 1]. Such observation highlights the importance of proper technique during pectus bar placement. Our review did not allow any conclusion as to whether or not failure to straighten the bar at the time of PBR was associated with an increased risk in complications.

4. Discussion

Within the last 20 years, many reports about tips and tricks as well as modifications during MIRPE resulted in a reduction of minor and major complications during pectus bar placement. However, only a few publications focused on PBR related complications. The aim of our study was to clarify why and when a pectus bar should be removed, where and how PBR should be performed and what PBR related complications have been reported.

Based on the literature and our own experience, there is general agreement that a pectus bar should be removed approximately 3 years after MIRPE. As described by Park et al. pectus bar removal may be individualized based on patient specific factor [20]. As already mentioned, we consider proper pectus bar placement as crucial precondition for safe PBR. MIRPE should be done under careful visualization by thoracoscopy, always having the tip of the introducer under direct visual control during retrosternal dissection, sternal elevation is important. Patients with previous cardiac surgery command special attention, in particular if there is no pericardium left. Furthermore, since it is possible to have unpredictable complications during PBR due to the very nature of MIRPE, PBR ideally should take place in the hospital setting where multidisciplinary care such as cardiac surgery is available in very short notice if needed.

Bleeding from intercostal artery injury and from internal mammary artery injury was reported as the most common cause of acute intraoperative hemorrhage during PBR [4]. Packing the bar tract and applying local pressure might be successful to control such bleeding [33]. However, depending on source and volume of hemorrhage, emergency sternotomy and/or thoracotomy might be necessary [Table 1] [4,23]. Besides vascular lesions, previous surgery (open heart surgery, previous Ravitch procedure, or thoracotomy), sternal erosion and lung injuries can be other sources of life-threatening complications [Table 1] [4]. Moreover, patients with a past history of infection and/or pericarditis should be considered at higher risk for life-threatening complications during PBR [2,43]. As summarized in Table 1, problems and complications experienced at the time of MIRPE may increase the risk of complicated PBR.

These observations are in contrast to the experience of Bilgi et al. who examined specific patients who had a perioperative complication which could increase the difficulties during PBR. Their experience with PBR in previously complicated Nuss procedures indicated that complications during the initial procedure do not predict further related complications during PBR [33]. In contrast, they noticed that double bar removals were associated with major complications, similar to the results of the survey of CWIG surgeons [2]. Pectus severity as well as pectus eccentricity with sternal rotation causing cardiac displacement into the left chest “behind” the sternum and deep/long sternal depressions (such as Grand Canyon types of deformity) represent conditions which need often more than one pectus bar, and such patients had an associated higher risk of complications during PBR [2]. Furthermore, the relevance of major post-operative bar displacement that can result in cardiac or vascular injury has to be considered, even if quite rare. Finally, patients with chronic pain after MIRPE must be carefully evaluated for the possible development of life-threatening complications [2] during PBR.

In general, reliable assessment of the true incidence of serious complications during PBR was not possible since there is no sufficient evidenced based data available in the current literature.

5. Conclusion

Pectus bar removal has a high safety profile but in rare cases may be associated with major complications such as life-threatening hemorrhage from various thoracic sources. This risk is higher in patients with a history of complex MIPRE. In an effort to decrease these complications we recommend bilateral opening of surgical incisions, unbending the bar and meticulous mobilization of the bar. To manage these complications if they occur, we recommend removal in a hospital setting with adequate resources and personal including cardiac surgeons. If the postoperative course is uneventful discharge on the same day is reasonable.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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