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The role and limitations of minimally invasive pectus excavatum repair: A single center 20-year experience

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Abstract

Background: Pectus Excavatum (PE) is the most common congenital deformity of the chest wall. Patients with severe deformities suffer from devastating physical, cardiac and psychological problems. Due to its heterogeneity, repair is generally not easy to perform, even with minimally invasive repair. The aim of this study was to investigate prognostic factors affecting the outcome in Minimally Invasive Repair of Pectus Excavatum (MIRPE).

Patients: A total of 370 consecutive patients admitted to our institution at the Ev. Hospital of Bethel, Bielefeld for PE between January 2006 and December 2025 were examined as part of a study investigating 20 years of experience performing MIRPE for patients suffering from severe PE since 2003. Type of deformity, severity, age, gender, symptoms, Haller index, pre- and postoperative respiratory function tests, pre- and postoperative echocardiography, body mass index, Bone Mineral Density score (BMD- score), pre- and postoperative quality of life of the patients, length of hospital stay and postoperative complications as well as long-term follow-up were analyzed.

Results: Between January 2006 and December 2025, there were 154 patients underwent MIRPE procedure. Ten cases were excluded due to incomplete data. The study included 144 patients (115 men, mean age 19±34 years). The median follow-up was 6.2 years. Excellent results were achieved in 92% (n=133), 5% had less satisfactory results (n=7) and 3% (n=4) had an unsatisfactory result. The reasons for unsatisfactory repair were: 1) rib fractures in older patients (age >30 years) (n=3), 2). Tear of the intercostal muscle due to severe deformity in older patients with high bone mass >3.5 kg (n=6) and 3) complex asymmetric deformity in older patients (n=2). Reoperation for repair was performed in 3 patients (2%). One patient had intraoperative ventricular fibrillations with successful resuscitation requiring admission to Intensive Care Unit (ICU) for 24 hours. The average length of hospital stay was 4 days. Minor complications occurred in 11% (n=16). Overall satisfaction was significantly high ($p<0.0001$). Timed removal of the pectus bar did not lead to recurrence of PE (n=0).

Conclusion: The MIRPE procedure for repairing the pectus excavatum is a safe and effective method. Although MIRPE is the gold standard for pectus excavatum repair, still are few patients with complex deformities who suffer from major incomplete or partial repair undergoing MIRPE. Age, severity of deformity and higher BMD-score are the most independent factors influencing the results regardless of gender.

Keywords: Pectus excavatum; Nuss procedure; Minimal invasive pectus excavatum repair; Chest wall deformity.

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Introduction

Pectus Excavatum (PE) is the commonest chest wall congenital deformity; it constitutes about 90% of childhood chest wall deformities with an estimated incidence of 1 in 400 births and prevalence of 2.6% in children age from 7 to 14 years [1]. PE affects 4 to 5 times more males than females. It is described by posterior depression of the lower third of the sternum. In the vast majority of the patients with serious deformation, pectoral muscles are accounted for to be underdeveloped [2]. Despite the fact that PE happens most commonly as solitary disfigurement, up to 20% of patients may have other skeletal abnormalities, most prominently scoliosis [3]. About one-third of the patients experience cardiopulmonary side effects. Most of them suffer from cardiac palpitations, Dyspnea especially during physical exercise, and in severe cases angina like symptoms. There is evidence to support that PE can alter physiologic function and decrease cardiopulmonary capacity, both at rest and with exertion. A new prospective study demonstrates that PE has an adverse effect on both cardiac and lung functions especially on the exercise capacity [4]. A large portion of the patients experiences psychological disorders because of their chest wall deformation. Social isolation, Depression and sometimes-suicidal attempts are not uncommon among patients with severe PE. The exact etiology of PE is still obscure, however its rate increments in patients with family history of chest wall intrinsic irregularities [5,6]. PE is radiographically classified according to the Haller Index (HI) (maximal transverse diameter/narrowest AP length of chest) which used to assess the severity of incursion of the sternum into the mediastinum. Normal Haller index is 2.5 or less. Significant pectus excavatum has an index greater than 3.5, representing the standard for determining candidacy for repair. In many patients, there are less cardiac symptoms than expected due to the compensatory functions in younger age. As the patients getting older many patients are under cardiac symptoms and some of them would even suffer from angina-like symptoms [7].

The surgical management intends to adjustment the thoracic wall disfigurement and the increase of cardiopulmonary capacities with prompts the improvement of the quality of life through the relief of the pressure on the heart and both lungs [8,9].

In 1998, an innovative strategy for repair of PE by utilizing a retrosternal bar; the so-called Pectus Bar (PB) without costal cartilage resection was described by Donald Nuss [10]. This procedure was created as a minimally invasive procedure to be the highest quality level technique for PE management [11,12]. The procedure is known as Minimal Invasive Repair of Pectus Excavatum (MIRPE). This technique has replaced other conventional procedures all over the world. In the last few years there were many modifications added to the original technique especially in term of side fixation.

One important issue in PE repair is the optimal timing of correction, which is yet to be clarified, although early repair has been reported to be associated with fewer complications, still, the golden age for correction is during adolescence years [13-15]. Asymmetric deformities, as well as the massive bone structure of the thoracic wall especially in elderly above 30 years, is associated with more complications and less repair satisfaction [16,17].

The aim of the present study is to lighten the lessons learned in the last 20 years and to demonstrate the challenges in various cases even in experienced hands. In this study, three cut points (Age, severity of the PE deformity, and bone mineral density score "BMD-score") were identified to be endpoints as regard, the outcome of surgery, quality of life and recurrence.

Data collection

Data of all PE cases were collected from our hospital records database, family doctors as well as direct patients contacts. Type of deformity, severity, age, gender, symptoms, Haller index, pre- and postoperative respiratory function tests, pre- and postoperative echocardiography, body mass index, Bone Mineral Density score (BMD-score), pre- and postoperative quality of life of the patients, length of hospital stay and postoperative complications as well as long-term follow-up were analyzed. For the purpose of this study, a quality-of-life questionnaire was developed and modified using the WHO- questionnaire for QOL and was sent to all patients with post or e-mail.

Follow up

Post operative follow up was constructed on a regular basis to include 5 visits to our out patients' facilities till the removal of PB. It was arranged with each patient in the form of outpatients' visits in the first 4 years postoperatively. After PB extraction, the follow-up was performed by personal contact in a large portion of the cases or by post.

Statistical analysis

Data were expressed as mean±SD or as count and percentage. Statistical analysis was performed using the student's t-test and a P-value<0.05 was considered significant for all analyses. The reference values for RFTs indices were based on age, gender, height, and weight. Non-parametric values were compared by the Wilcoxon's signed sum rank test.

We analyzed the results from the SSQ and compared the results with those obtained by the NQ-mA test, which we considered as an adequately validated reference questionnaire. Spearman's correlation coefficient was used to assess the correlation between the answers received on the test-retest study, the correlation between the total scores obtained from the post-operative NQ-mA and the SSQ, and finally, the correlation between the net gain in total scores from the NQ-mA and the SSQ. Spearman's correlation coefficient value of 1 indicates complete agreement. Propensity score matching was used to adjust for differences in baseline characteristics. Descriptive statistics were presented for all patients and propensity-matched patients using a logistic regression model that included twelve variables: Age, sex, symmetry of the deformity, severity, Bone mineral density score (BMD score), lung function tests, dyspnea scale, ASA score, length of operative time, complications, length of hospital stay, recurrence. Results were expressed as mean±SD for patients' characteristics and other variables. A statistical difference with P<0.05 was considered significant.

The SPSS software (IBM-SPSS Inc, Chicago, IL, USA, version 22) was used.

Patients' selection and study design

We analyzed the data of all cases who were seeking repair for their PE at our institution between January 2006 and December 2025. To avoid structural bias, this study was limited to include only patients who operated on in the same center through the same surgeon over the whole period. A total number of 370 patients were examined for PE at our institution. MIRPE was performed on 154 patients. The data of this group of patients were thoroughly analyzed. Ten patients were excluded from the study due to incomplete data.

According to their age, patients were divided into three groups. Group 1 consisted of 72 patients younger than 20 years old. Group 2 consisted of 42 patients at age between 20 and 30 years. Group 3 consisted of 30 patients older than 30 years.

All patients received the usual preoperative work up in form of Posteroanterior (PA) and Lateral (LT) chest X-ray, chest Computed Tomography (CT) or Magnet Resonance Tomography (MRT), Echocardiography (Echo) and Respiratory Function Tests (RFTs). Few patients received chest Magnetic Resonance Tomography (MRT). Haller Index (HI) was calculated on CT or MRT and used to define the degree of deformity. The bone meniral density score was calculated using X-ray (Figure 1A,B).

Most of the patients received six postoperative follow up in the following intervals: 2 weeks after discharge from the hospital, 3, 6, 12 and 24 months, then the last follow up was to determine the timing for Pectus Bar (PB) removal.

Operative techniques

MIRPE, which was first described by Donald Nuss, Virginia USA, was performed for all patients. Numerous recommendations from different published papers were implemented for prevention of PB rotation or dislocation. All patients were operated on in the supine position with abduction & external rotation of both arms under single lumen intubation. A bilateral anterior-axillary skin incision was done (length: 2-3 cm). A sub mascular tunnel was made to reach the highest point at the para sternal line using the curved metal guide. The metal guide was introduced in the fourth or the fifth inter costal space retrosternal from right to left. The tip of the metal guide is the identified on the parasternal line on the left side. One or more retrosternal convex metallic bars (pectus bars) were exactly measured using a stencil, bent according to body size, and inserted under the Video Assisted Thoracoscopic (VATS) guide and withdraw from left to right using the metal guide after connection using a thick Ethibond, Ethicon band (Figure 2A,B). On both ends of the bar, two side stabilizers were fixed with metallic wire. The measurement was done as depicted by Donald Nuss, the length of the PB was 2 inches less than the line from one axillary line to the other. PB was settled with two stabilizers on both sides utilizing metal wires. Only in case of instability of the PB, we used to fix the bar with metal wires around the rib (3 points fixation). Few patients especially older than 30 years, 2 pectus bars were used to achieve better correction. In the last 3 years we used to use another type of pectus bar due to easer way of insertion (Figure 3A,B; Figure 4A,B).

Results

Patients' characteristics

From the patient's database of our center, 370 consecutive patients were admitted and evaluated for PE repair. MIRPE was performed on 154 patients 10 patients were excluded due to incomplete data. The study included 144 patients. There were 105 males (73%). Group I consisted of 72 patients, mean age 16 (range 7-20 years) with mean BMI of 18, 4 (range 11, 2-25, 6), and the mean BMD-score: 2,6 Kg (range 2-3, 2). The mean HI was 3.9 (range 3.1-6.8). Group II consisted of 42 patients, mean age 26.5 in group II, range (20-30 years) with a mean BMI of 22, 4 (range 18, 2-31, 4), and the mean BMD-score of 3, 2 kg (range 2, 6-3, 9 kg). The mean HI was 3.9 (range 3.5-5.7). Group III consisted of 30 patients, their mean age 37.5, range (30-53 years) with a mean BMI of 26,4 (range 21, 2-33, 4), and the mean BMD-score of 5,1 kg (range 3, 2-6, 7 kg). Median follow up in all patients was 6.2 years. Patients' characteristics are given in (Table 1).

Echocardiography & lung functions tests

They were performed preoperative and 6 months after the operation. The mean Forced Expiratory Volume in 1 second (FEV1) was 78% (range 64%-93%). The mean Vital Capacity (VC) was 85% (range 65%-105%). Post-operative lung functions especially the FEV1 showed better values in comparison to preoperative values in 78% (n=113), no change in 17% (n=25) and less values in 5% (n=6) (Figure 5). Restrictive values were noticed in 65% (n=85) preoperatively, which was noticed only in 12% (n=16) in the post-operative follow-up ($p<0.001$).

Preoperatively, ECG was done in 88% (n=115) of the patients and transthoracic echo in fewer patients 46% (n=32) who had changes on ECG or suffering from severe deformity. The postoperative cardiac examination was done with the 6 months follow up timing. The most common abnormalities found on ECG and or echocardiography were: [i] dislocated apex of the heart much to the left (56%) (n=74), [ii] right bundle branch block (25%), [iii] left bundle branch block (16%), [iv] extrasystoles (8%), and [v] Angina-like findings 1%. All the cardiac findings disappeared on ECG and echocardiography apart of the right bundle branch block which persisted in 2 patients (1.5%).

Operative results

Excellent results were obtained in 92% (n=133), 5% had less satisfactory results (n=7) and 3% (n=4) had unsatisfactory repair. The reason for unsatisfactory repair was failure to correct the PE to the wish position due to intraoperative rib fracture during the elevation of the sternum using the sword. In these 3 patients, the PE deformity was very severe, their age ≥35 years, and had a calculated BMD-score >3.5 Kg.

Reoperation due to PB displacement or unsatisfactory results was done in 3 patients (1,3%). Minor complications occurred in 11% (n=16): there were 5 patients (3,4%) who developed postoperative pleural effusion (3 on one side and 2 in both sides. 4 of them needed a chest tube, none was re-operated on due to pleural effusion. There were 9 patients with pneumothorax between 1-5 cm postoperatively or after chest tube removal. 3 patients needed chest tube re insertion, and in 6 patients' pneumothorax was resorbed after administration of 3-4L of O_2

supply on the nose. Other minor complications were observed in 3% (n=5). Mean hospital stay was 4 days in group I (range 3-6 days) vs 5 days in group II (range 5-11 days) and 8 days in group III (p=0.031). One patient had to be admitted to the ICU due to intraoperative ventricular arrhythmia of unknown origin, which was at once successfully converted using intraoperative electrical shock. Removal of PB was done in 51 patients in group I vs. 24 in group II and 10 in group III. No recurrence of PE was noticed in all patients after removal of PB in all groups.

Patient's satisfaction

There were 144 questionnaires were sent to the patients, patients were asked to fill in and return it back either by mail or e-mail or fax. There were 112 questionnaires returned, but 8 were not suitable to analyze due to missed or undefined data. 104 questionnaires were analyzed and subjected to comparison in both groups. There was very high patients' satisfaction in group I and II comparing with group III (p=0.012). Patients with pain more than 6 months were 1 in group I, 3 in group II and 6 in group III (p=0.019). No patient answered with yes to the question if he/she would not do the operation or recommend it for somebody else (p<0.000I). The distant between the posterior wall of the sternum and the anterior wall of the spine. 94% (n=68) in group I answered with yes for good/normal body feeling postoperatively compared with 12.5% (n=9) preoperatively (p<0.001). In group II 83% (n=35) answered with yes for good/normal body feeling postoperatively comparing with 7% (n=3) preoperatively (p<0.001). In group III 65% (n=13) answered with yes for good/normal body feeling postoperatively comparing with 7% (n=2) preoperatively (p<0.011).

Table 1: Preoperative characteristics.

Patient characteristics	Results	P
Age years (mean±SD)	56±14 years	
Gender		
-Male	115(82%)	0.018
- Female	25(18%)	
Race, n (%)	125(89%)	0.005
- Caucasian	15(10%)	
- Hispanic Smoking status n (%)	102(73%)	0.011
- Never smoker	38(27%)	
- Smoker/previous smoker Deformity		
- very sever	68(46%)	0.032
- severe	57(40%)	0.044
- Moderate	15(10%)	0.021
Complexity		
- Symetrical	81(46%)	0.022
- Non symmetrical	34(24%)	0.027
- Komplex	25(18%)	0.016
Palpitation	78(55%)	0.004
Dyspnea score (MRC), n (%)		
2	25(18%)	
3	110(78%)	
4	5(3.5%)	

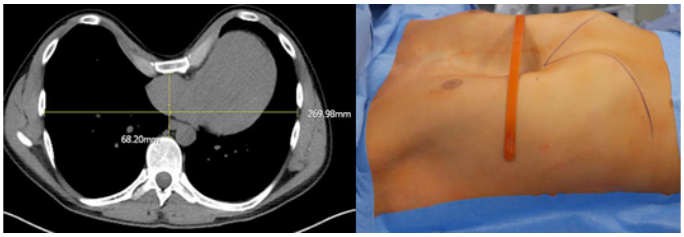

Figure 1: (A) CT-scan of the chest with severe pectus excavatum deformity. **(B)** Topographic demonstration of the pectus excavatum deformity.

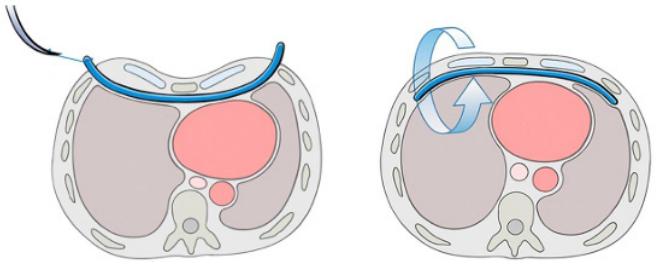

Figure 2: Demonstration of the insertion of pectus bar and its rotation.

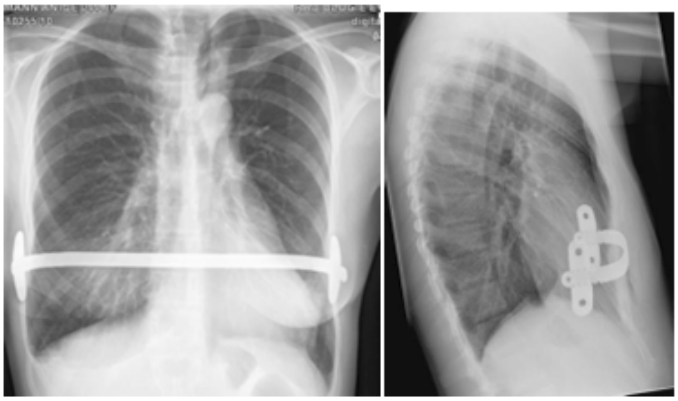

Figure 3: Chest X-ray in posterior-anterior and lateral position after correction using the old pectus bar.

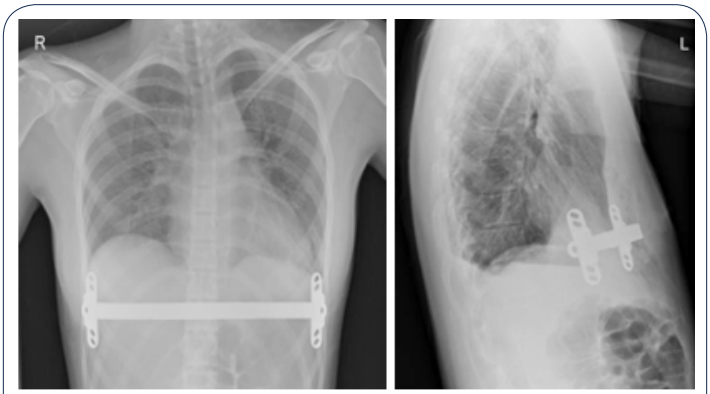

Figure 4: Chest X-ray in posterior-anterior and lateral position after correction using the new pectus bar.

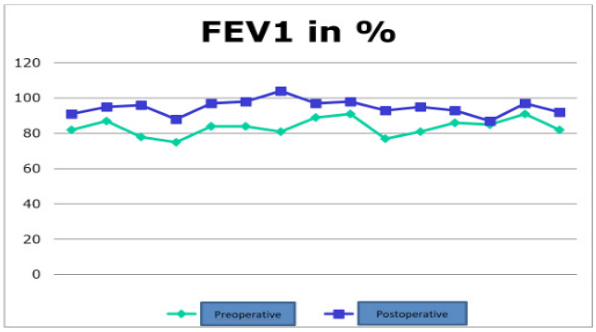

Figure 5: Pre and post operative lung functions; Forced Expiratory Volume in 1 second (FEV1).

Discussion

Pectus Excavatum (PE) and carinatum are the most widely recognized thoracic cage anomalies. They often coincide with the vulnerable life phase of puberty, a period characterized by great physical, social, and emotional changes. PE either can be present at birth or may develop and deteriorate during childhood and adolescence [18].

The main symptoms associated with PE are due to cardiac compression as well as restrictive lung functions. In this study, open cardiac bypass was performed on a 42-year-old female patient due to devastating angina-like symptoms. Six weeks later, the patient developed the same symptoms and was readmitted to the heart center, where a diagnosis of Pulmonary Embolism (PE) was made. After correcting the deep PE using MIRPE, her symptoms disappeared. Over the last 2 decades, the MIRPE was commonly used all over the world replacing most of the conventional methods known. Nowadays it is the gold standard for the treatment of PE. Excellent results were obtained in 92% (n=120), 5% had less satisfactory results (n=6) and 3% had unsatisfactory repair (n=4). Our results were similar to that seen by Kelly stated that satisfactory results were recorded in 93.8% of cases and even 6.2% had worsening of their conditions [19]. In our study, no worsening of the deformity was reported.

Nevertheless, MIRPE has its limitations especially in case of complex deformity e.g. the combination of PE and carinatum, PE with one side deformity of the ribs, PE combined with costal margin deformity or PE in an elderly patient with large sized thorax and heavy bone structures of the sternum. Better results after correction of the PE depends not only on the degree of deformity but also on the age as well as on the BMD-score. Donald Nuss presented his series with 10 years of follow up in 1998 with a very young patient population (1.5-15 years) [10]. There were many modifications of the original Nuss procedure, some of them are useful, and some are of no benefit. We agree with authors who reported that stabilizing of both ends of the bar using side stabilizers are most important [20,21]. We disagree with authors who suggest 3-point stabilization for each patient [4,15], as this is in many patients with symmetrical deformity even if it is severe are not necessary. We disagree with Pilegaard and Licht [22] about the use of shorter bars, as this was shown through other authors that it leads to higher incidence of rotation and flipping of the bar [23]. Asymmetrical PE or complex thoracic wall deformities need not only correction of PE using the Nuss procedure but much more modifications and combined surgery. Most of the publication before 2010 did not address these difficulties, very rare discussion and nearly no consensus in the literature about how to manage complex deformity, especially in an older patient with heavy sternal bone density undergoing MEPE. In such patient with the rigid and heavy sternum, losing the lever effect scenario after rib fracture is common. This is a challenging situation for the surgeon. Therefore, we suggest elevating the sternum before introducing the metal guide; this is an important factor to avoid rib fractures. The median age of our study group was 21 years. This was older than that seen by other authors, where the median age was 14 years and 15 respectively [20,24].

Still little was reported about limitations of MIR in elderly patients with asymmetric deformity and how to deal with it. In our experience, the best age for MERPE was between 14 to 25 years old, and especially in patients with less BMD-score and BMI. Younger patients (<12 years) who have no cardiopulmonary symptoms should be advised to wait with the correction of their PE to avoid a second operation for a bigger bar size after two years due to size mismatch with their rapidly growing thoracic cage. Our results showed a mean HI of 3,8 which is less than reported by other authors but still high on itself. In our study, we found a significant correlation with the higher HI and the use of more than one PB. Also, there was a significant correlation with the higher HI and the presence of cardiopulmonary symptoms, which was noticed by other authors as well [24,26]. In this study, we noticed that the higher the HI, the higher the incidence of cardiac symptoms.

Cardiac symptoms were mimicking angina pectoris in one female patient aged 41 years old in whom the HI was 4,8. She developed signs and symptoms of angina pectoris due to compression of the right coronary artery, which was asses as a coronary artery closure. She underwent open cardiac surgery and bypass of the right coronary artery. The postoperative course after her cardiac surgery was uneventful but her symptoms persisted. On the advice of her cardiologist, she sought our institution for correction of her PE. After PE correction with using MIR, all her cardiac symptoms have gone and showed no any signs or symptoms of angina pectoris anymore.

We noticed a significant correction of the RFTs in most of the patients underwent MIR. Preoperatively, 45% of our patients showed restricted lung functions with less FEV1 than expected, which were corrected in most of the patients (87%) after the correction of the PE. Many young patients with FEV1 less than 95% are subjected to suffer from early deterioration of their RFTs in earlier ages than other individuals who have the same life conditions without PE. Therefore, one has to advise them for correction of PE even if the FEV1 and the VC are still in better conditions. Although the effect of MIR on the cardiopulmonary functions is still controversial, we noticed that most of the cardiopulmonary symptoms were relieved. The preoperative cardiopulmonary data showed significant improvement in the postoperative work up 6 months after the operation and later on, these findings were reported earlier. To proof these retrospective findings, prospective studies are needed.

Use of shorter bars was described by Pilegaard, did not find much acceptance between surgeons with more experiences. Also, the 3-point fixation around the ribs and the sternum to avoid hinge

point displacement is still unpopular because of its accompanying complications as well as little evidence of its benefit [27].

The mean follow up of our study was 5.2 years, which is longer than reported before [25]. Only one patient has pain after 9 months postoperatively, which reported to be new. All other patients showed no symptoms after 6 months postoperatively. Usually, we leave the PB for 3 years duration in younger patients (≤25 years) and 4 years in older patients. Moreover, no recurrence after PB removal was noticed over the follow- up period.

Conclusion

In conclusion, MIRPE is the gold standard of care for patients suffering from symmetrical PE. In case of severe asymmetrical deformity especially in older patients, with high BMD score every care must be taken to avoid rib fractures and bar dislocations. All patients must be informed of the limitations of MIRPE, especially those over 30 years of age.

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