General Thoracic and Cardiovascular Surgery
https://doi.org/10.1007/s11748-023-01940-9

ORIGINAL ARTICLE

Modification of the Nuss procedure: the crossed bar technique for new subtypes of pectus excavatum

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Received: 9 March 2023 / Accepted: 4 May 2023

Abstract

Background We aim to describe four new subtypes of PE in detail and represent modification of the Nuss procedure called crossed bar technique for their optimum correction with good results.

Methods 101 patients who underwent crossed bar technique between August 2005 and February 2022 were included into the study.

Results The mean age of the patient series was 21.1 (range 15–38 years) years. Mean Haller index was 3.87. Mean operation duration was 86.84 min. 2 bars were used in 74 (73.3%) of the patients whereas 3 bars were preferred in 27 (26.7%) of them. Mean hospital stay was 4.1 (2–8) days, and all the patients were seen routinely on postoperative follow-up at 1st, 6th, and 18th months. Quality of life questionnaires revealed satisfaction.

Conclusions Cross bar technique yields satisfactory results for these new subtypes and can be performed safely with good results in these selected group of patients.

Keywords Pectus excavatum · Nuss procedure · Minimally invasive repair · Chest wall deformities · Pectus carinatum

Introduction

Pectus excavatum (PE) is the most common anterior chest wall deformity with an occurrence of 0.3% of all births [1, 2]. In a recent publication, Biavati and friends published the population-based prevalence of pectus excavatum in adults as 0.4% [3]. The first publication of the deformity in the literature had been reported by Eggel in 1870 and he identified the deformity as a depression of the anterior chest wall [4]. Moreover, Kwiecinski et al. reported the evaluation of computed tomography (CT) scans of 217 mummies in which three PE cases were detected [5]. This information reveals the presence of the deformity in antique times with similar prevalence up to date. Even though there are some theories, etiology is not clear yet [6]. Almost all the existing data report a higher frequency of men versus women with a proportion of 5: 1 [7]. Although Ravitch sternoplasty is the conventional correction method, surgical approach switch towards minimally invasive technique after Dr. Nuss's first publication in 1998 [8]. Minimally invasive repair of PE (MIRPE) became widely accepted and patients with various types of deformities started to emerge. Recognition of the new subtypes of the deformity opened a new chapter in the field of chest wall deformities. In addition to that, it also showed that one type of minimally invasive repair surgery does not cover the needs of all the patients. Thus, new improvements and modifications of the technique were developed by the surgeons. The main purpose of our data is to describe new subtypes of the deformity and raise awareness for the detection of them in this diverse group of patients. Additionally, we also want to draw attention to the surgical treatment of these subtypes with a specific modification for optimum care with better results and outcomes.

Here, we identify new subgroups of PE which are treated with a specific modification of the Nuss procedure called the crossed bar technique. We briefly share the description and evaluation of the subgroups along with indications and preoperative/postoperative results of the new surgical technique. This is the first report describing specific groups of PE patients in detail who underwent a new modification of the classical minimally invasive repair.

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Published online: 14 May 2023

Methods

1089 patients, who had been treated with MIRPE between August 2005 and February 2022, were reviewed retrospectively from a database. This study was approved by ethics committee of our center. Among them, 101 patients who underwent crossed bar technique were included into the study. As we performed the first crossed bar technique in 2017, time span for these 101 patients is 62 months. All data regarding evaluation, demographics, type of the deformity, comorbidities, number of the bars, preoperative and postoperative complications, length of hospital stay, quality of life questionnaire and follow-up have been recorded. Additionally, preoperative, and postoperative pictures of the patients were taken for the archive in every encounter with them. Furthermore, all the patients receive quality of life questionnaire at the 6th postoperative month. Our pectus surgery program does not include CT scan of the chest in the preoperative assessment of the patients. Only symptomatic patients, patients with syndrome or anomalies or patients with history of previous pectus surgery undergo CT scan. None of the patients were excluded during the study. Satisfactory result is defined as desired optimum flat correction during surgery that is verified by results of quality-of-life questionnaire at 6^{th} postoperative month.

Statistical analysis

Statistical analyses were performed using statistical software (SPSS, version 25.0 for Windows; SPSS, Chicago, Illinois, United States). Discrete random variables were presented as percentage and continuous random variables were presented as mean and range (max–min values).

Surgical indications

We described four different subtypes of pectus excavatum as indications for crossed bar procedure.

1. PE with rib flare group (Group 1); includes those with remarkable bilateral or unilateral protrusion of costal arch ribs (Fig. 1a).
2. PE with sharp and one point of depression group (Group 2); includes patients who have pinpoint depression with narrow base (Fig. 1b).
3. PE with short length sternum group (Group 3); includes patients with relatively short sternum in comparison to very long chest wall (Fig. 1c).
4. Grand Canyon type PE and short length sternum group (Group 4); consists of patients with short sternum who also have an accompanying Grand Canyon type deformity. (Fig. 1d).

Surgical technique

After induction of general anesthesia and insertion of an intubation tube, the patient is positioned supine with the flexion of the right arm anteriorly adjacent to the head. The chest is carefully palpated, and the deepest point of the depression is marked with a marking pen. Following the marking and measurement, proper template and bar size is determined. Template is formed according to the chest wall that is desired after the operation. Bar is bended to match the template by using hand or table benders. 2 cm vertical incisions were made on both sides at the anterior axillary line. A separate 0.5 cm incision is made at the right posterior axillary line inferior to the previous incision to place the thoracoscope. Then, the introducer is inserted through

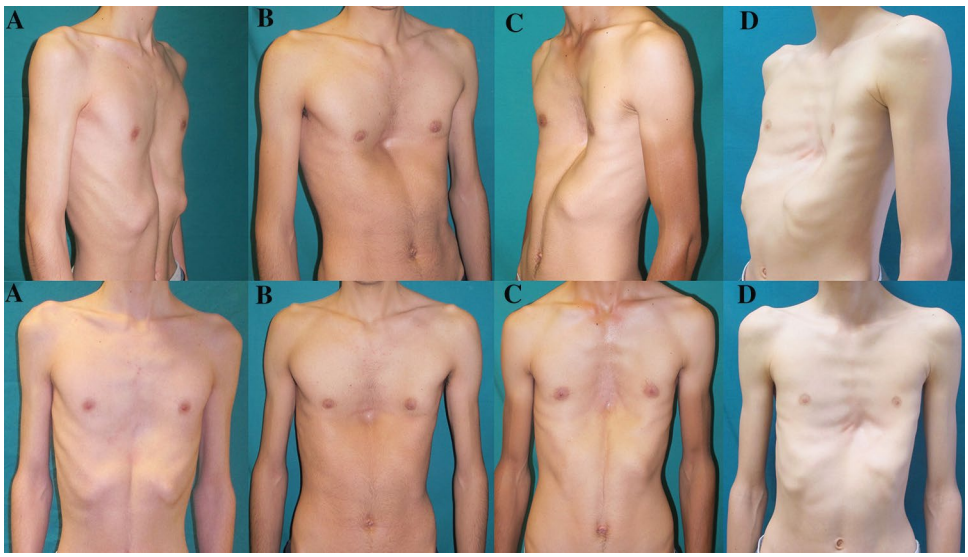

Fig. 1 Images of the subtypes of PE. **A** PE with rib flare group (Group 1) **B** PE with sharp and one point of depression group (Group 2) **C** PE with short length sternum group (Group 3) **D** Grand Canyon type PE and short length sternum group (Group 4). *PE* Pectus excavatum

the right incision and forwarded through the contralateral hemithorax. A tape is tied up to the formed pectus bar and the pectus bar is inserted to the right hemithorax. It is passed through the tunnel and taken out from the thoracic cavity in an upside-down position. Bar is then rotated 180° by the bar rotators and brought to the position it should be for correcting the deformity. After the implantation of the bar, it is fixed to the chest wall by the aid of the stabilizer. Same steps of the procedure are repeated for the second or third bars. Decision for making additional incisions for the other bars depends on the size of the chest wall. Finally, the air is drained through a suction catheter introduced from the camera port from the right pleural space. Therefore, there is no need for chest tube insertion. Inserting the bars in a crossed manner might be challenging especially during the learning curve period. These subtypes are advanced and atypical cases, so it is more dangerous to go through the presternal mediastinal area. It is important to start inserting from the right upper side and go dissecting relatively on the wider part of the presternal mediastinal area. Thus, inserting the first bar will enlarge the presternal narrowest area (deepest point of the deformity) by elevating the sternum and make it easier and safer to insert the second bar through the pressed mediastinal tissue without harming pericardium or heart. Additionally, the appliance of an extensive force might cause the bars to rupture intercostal muscles during stabilization part of the surgery. Intraoperative use of crane or vacuum bell device might help to avoid rupture of the intercostal muscles by reducing the resistance of the sternum and need for force during correction. The other important point is the localization of the stabilizers. It is important to locate the body of the stabilizer onto the superior border of the upper rib in the intercostal space where the bar is inserted. Otherwise, placing it close to the inferior border of the upper rib increases the risk of sliding of the stabilizer and bar displacement. The major advantage of the technique is the long-term maintenance of the correction. In the beginning of our series, we tried to correct these subtypes with standard techniques, but we observed recurrence of the deformity in the long-term follow-up period. We believe that the proportional distribution of the force applied by the bars in this technique provided more efficient force to prevent recurrence. In the other techniques, the momentum of the force is applied to a limited part of the chest wall which ends up with recurrence or failure. The other advantage is the pressure applied by the tips of the bars to the flaring ribs. In the other techniques, flaring ribs become more prominent after the elevation of the sternum with correction. On the other hand, some disadvantages exist. Due to the widespread distribution of the force applied, patients have a more painful postoperative period in the first couple of days following surgery, but this does not affect the average length of hospital stay in comparison with the other MIRPE patients. Our data showed a mean length of hospital stay as 4.1 (2–8) days which was consistent with the existing literature and our global data.

In addition to that, patients who are treated with crossed bar technique are more prone to have pleural effusions postoperatively compared to other patients.

Video-1 describes technical steps of crossed bar technique.

Results

The mean age of the patient series was 21.1 (range 15–38) years. Our series were male dominant with 84 patients (83.2%). 77 (76.2%) had symmetrical deformity, while 24 patients' (23.8%) deformity were asymmetrical. 1 (1%) patient had scoliosis, the other patient (1%) had hypothyroidism and another patient (1%) had Wolf-Parkinson-White syndrome as accompanying anomalies. 4 (3.96%) patients had a previous pectus surgery which ended up with unsatisfactory results. These unsuccessful attempts include Nuss procedure for 2 patients and Ravitch sternoplasty for the other two patients. On the other hand, there were five (4.95%) patients with past surgical history. One patient needed tube thoracostomy due to spontaneous pneumothorax, one patient had appendectomy, one patient underwent adenoidectomy, one patient had blepharoplasty and the other patient underwent rhinoplasty.

The demographic and preoperative characteristics of the patients are shown in Table 1.

Mean Haller index and mean Correction index were 3.87 and 0.33, respectively. Indication for surgical correction was cosmetic concern for all the patients. Echocardiography or pulmonary function tests were not routinely requested unless patients had a suspicion for cardiac or pulmonary disease. Mean operation duration was 86.84 min with range of 60 to 180 min. The length of the bar varied from 8.6 to 14.8 inches. 2 bars were used in 74 (73.3%) of the patients whereas 3 bars were used in 27 (26.7%) of them. 2 bars were enough to repair the deformity in Group 1–3 but another apical third bar needed for satisfactory correction in Group 4 patients. Successful analgesic regimen was maintained for adequate pain control after surgery. Intravenous patient-controlled analgesics (IV PCA) were used for 3 days after the surgery and switched to oral analgesics afterwards. Postoperative mean Haller index was 2.22 (1.87–2.50). Morphine was used as the analgesics in PCA protocol and combination of opioid analgesics (tramadol), NSAID and paracetamol was preferred as oral analgesics after postoperative third day. Our data showed a mean length of hospital stay as 4.1 (2–8) days which was consistent with the existing literature and our global data. Figure 2 shows the preoperative and postoperative pictures of some of the patients.

Table 1 Patient demographics and preoperative characteristics

Number of the patients	101
Age (year)	21.1 year (15–38)
Sex (*n*)	
Female	12 (10.5%)
Male	84 (89.5%)
Haller index	3.87 (3.5–7.2)
Correction index	0.33 (0.13–0.72)
Type of the deformity (*n*)	
Symmetrical	77 (76.2%)
Asymmetrical	24 (23.8%)
Group of the deformity (*n*)	
I	19 (18.8%)
II	16 (15.8%)
III	39 (38.6%)
IV	27 (26.7%)
Comorbidities (*n*)	
Scoliosis	1 (1%)
Hypothyroidism	1 (1%)
Wolf–Parkinson–White syndrome	1 (1%)
Past surgical history (*n*)	
MIRPE	2 (1.99%)
Ravitch sternoplasty	2 (1.99%)
Tube thoracostomy	1 (1%)
Rhinoplasty	1 (1%)
Blepharoplasty	1 (1%)

[a]The values are presented as a number (the percentage of variables) or the mean value (range). *MIRPE* minimally invasive repair of pectus excavatum; *mo* month

Mean hospital stay was 4.1 (2–8) days, and all the patients were scheduled routinely postoperative follow-ups at 1st, 6th, and 18th months. The intraoperative and postoperative data are summarized in Table 2.

We experienced some early and late postoperative complications. Pleural effusion (six patients–5.94%) and pneumothorax (five patients–4.95%) can be listed as the most common early complications. Only three of those patients needed chest tube insertion for treatment. Wound infection was detected in 6 patients (5.94%) as the leading late complication. Among them, one of those patients was treated conservatively with antibiotics while the other 5 patients needed minor surgical intervention for the management. On the other hand, 1 (1%) patient underwent early removal of one of the bars due to chronic serous drainage from skin incision and one (1%) patient needed early removal of both bars because of intractable pain. 57 of 101 patients (56.45%) have undergone bar removal surgery as a part of the elective schedule which is basically 3 years after correction surgery. All patients completed Quality of life questionnaire on the on the 6th postoperative month and 99% of them reported satisfaction. We did not experience any mortality or life-threatening complications at all. Figure 3 demonstrates postoperative complications and results of quality-of-life questionnaires in detail.

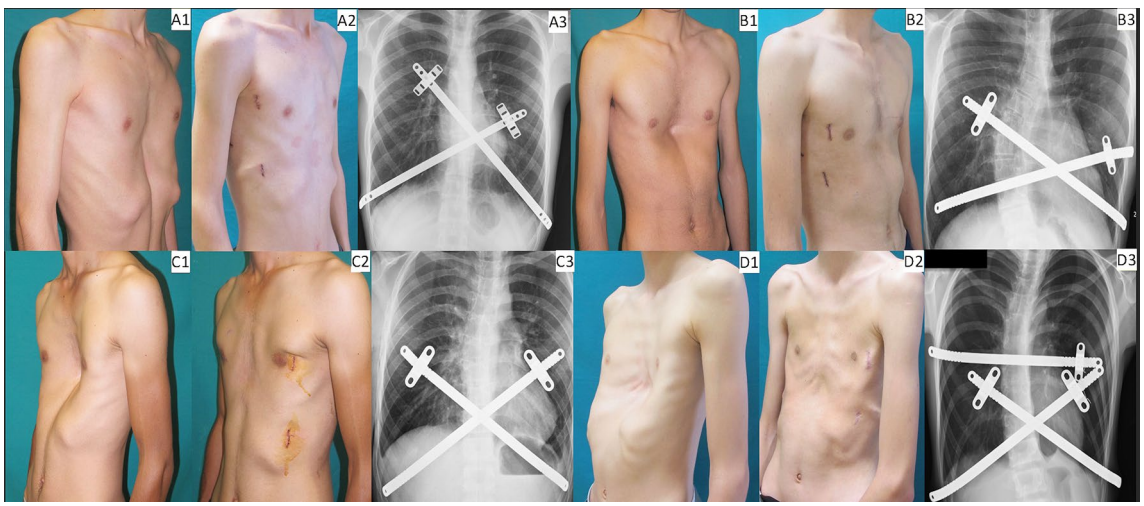

Fig. 2 Preoperative and postoperative images and postoperative chest x-rays of the patients. **A** a1 Preoperative image of Group -1 patient, a2 Postoperative image of Group -1 patient, a3 Postoperative chest x-ray of Group-1 patient. **B** b1 Preoperative image of Group-2 patient, b2. Postoperative image of Group-2 patient, b3. Postoperative chest x-ray of Group-2 patient. **C** c1 Preoperative image of Group-3 patient, c2 Postoperative image of Group-3 patient, c3 Postoperative chest x-ray of Group-3 patient. **D** d1 Preoperative image of Group-4 patient, d2 Postoperative image of Group-4 patient, d3 Postoperative chest x-ray of Group-4 patient

Table 2 Intraoperative and postoperative information

Number of the patients	101
Mean duration of surgery (min)	86.84 min (60–90)
Length of bar (inch)	11.2 inch (8.6–14.8)
Number of the bars (*n*)	
2 bars	74 (73.3%)
3 bars	27 (26.7%)
Mean LOS (day)	4.1 days (2–8)
Early postop complications (*n*)	
Pleural effusion	6 (5.95%)
Pneumothorax	5 (4.95%)
Late postop complications (*n*)	
Wound infection	6 (5.95%)
Chronic serous drainage	1 (1%)
Intractable pain	1 (1%)

[a]The values are presented as a number (the percentage of variables) or the mean value (range). *LOS* length of hospital stay; *min* minute

Discussion

MIRPE became the gold standard for surgical correction of PE [9–11]. In the first decade of the MIRPE era, surgeons approached all PE cases as one type of deformity. As a result of this mentality in assessment; they aimed to correct all of PE patients by the same type of MIRPE technique. Unfortunately, this misconception ended up with lots of patients with insufficient correction or unsatisfaction who were even sometimes necessitated redo surgeries for correction [12, 13]. Thus, this experience showed that spectrum of PE deformities is beyond existing data. Over the years, there have been several publications of different modifications of MIRPE from different centers all over the world [14–16]. Almost all those modifications offered better results for standard type of PE deformities, but they did not mention which modification is indicated for which subtype of the deformity. Although some centers published some classifications and indices for PE, none of them have gained widespread acceptance in the routine clinical practices [17–19].

We described four subtypes of PE, which can be best corrected with a specific type of modification of the MIRPE, first time in the literature. Group 1 includes those with remarkable bilateral or unilateral protrusion of costal arch ribs. Crossed bars enable tips of the bars pressing on the protrusions of costal margins and limit further elevation of them due to force applied for correction. Group 2 can be described as patients who have pinpoint depression with narrow base. The reason for failure in this group of patients with standard technique is that the bars slide up or down secondary to the shape and angle of the sharp pinpoint deformity and widened intercostal spaces. Therefore, bars cannot apply force to the very deep sharp point. Thus, utilization of two bars in a crossed manner is needed for adjusting the momentum of the forceful push for optimal correction. Group 3 is basically consisting of patients with relatively short sternum in comparison to very long chest wall. The main problem in these patients is that there is not enough area of sternum inferiorly for the bar to be able to apply force efficiently. Crossed bars receive support from the rib cage, which is located the superior to the deformity, by reaching to both upper and lower parts of the chest wall. Thus, efficient force with an optimized momentum can be maintained for fixing the deformity. Group 4 includes patients with both short length sternum and Grand Canyon type PE. Grand Canyon type PE can be defined as a deep wide longitudinal groove running from the clavicle all the way down to the lower chest which most of the depression is in the parasternal cartilage not in the sternum. This group is separated from Group 3 because of the need for the third parallel bar for the correction of the wide based Grand Canyon type PE in addition to the repair of PE with short length sternum. We only

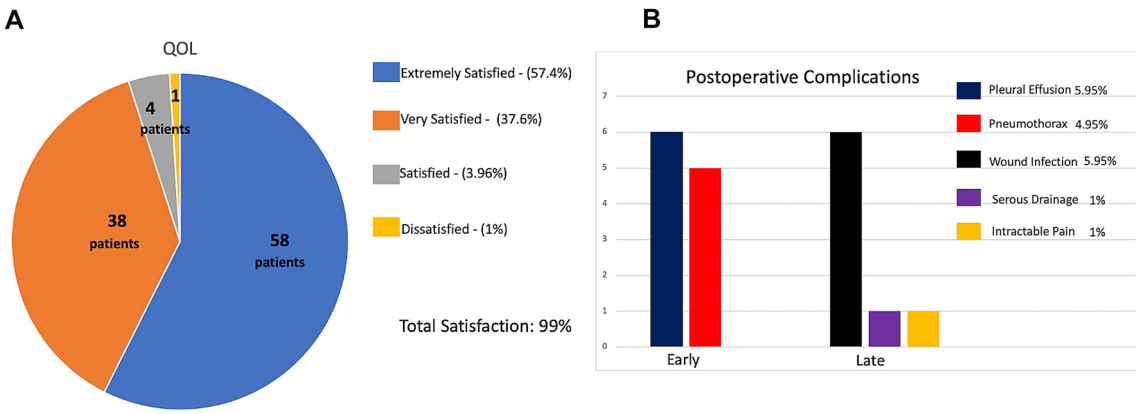

Fig. 3 **A** The results of quality-of-life questionnaires. **B** Postoperative complications following crossed bar technique. *QOL* quality of life

needed an additional apical parallel bar for correcting the extensive superior part of the deformity in Group 4 patients due to having a Grand Canyon type component in this subtype. Although it is optimal to correct the inferior part of the deformity with crossed bars, an additional apical bar is useful for the favorable outcome due to the formation of the Group 4 subtype. It is certainly more advantages to correct the deformity with single or double bars if it is possible.

All our groups (Group 1–4) necessitate focused force and momentum for optimum correction. Cross bars will keep providing this upwards push by supporting each bar the other for long time in order not to experience those undesired outcomes.

On the other hand, chest wall rigidity of pediatric population is different than adult population by being less rigid and firm due to ongoing bone maturation process. Therefore, even though these subgroups exist also in the pediatric PE population, the use of cross bar technique is limited to only group 1 patients.

Even though there are few case reports regarding the use of crossed bars, its indications and clinical implications are still unclear. Dr. Park reported a case report including one patient who underwent cross bar technique for repair [20]. Unfortunately, he just addressed this technique to Grand Canyon type PE and did not give much insight about indications and outcomes. Although Dr. Darlong recently published a case report of PE patients who were treated with crossed-bar technique, these data were not enough to establish a consensus on the clinical implications of crossed-bar technique due to the limited number of patients [21]. Also, there are some recent publications pointing out the importance of crossed bar technique. Moon et all reported their data comparing results of surgical correction with parallel bar insertion ($n=44$) and crossed bar insertion ($n=36$) and they focused on the mechanical parameters of both techniques [22]. Although they mentioned wider and lower located deformities as indication, they did not specify any types or subtypes. In addition to that their crossed bar population include patients younger than 18 years old which is different than our results. Because we advocate that even though these subtypes exist in the patients younger than 18 years old, they do not need crossed bar technique due to having more flexible chest wall. Hyun and friends also published an article comparing the result of 157 crossed bar patients with 90 parallel bar patients [23]. They described some features as indication but did not simplify it with clear description and patient pictures.

Our study is the first report in the literature describing well-defined subtypes of PE deformities that are treated with specific type of the modification of MIRPE with high satisfaction rates and good cosmetic results. It also highlights the importance of not performing the same type classic Nuss surgery for every pectus deformity and raises awareness for evaluating every single case carefully to detect the subtypes. There are some limitations of the study. We did not compare the outcomes and results with the results of other MIRPE patients. We designed this study in a descriptive pattern for defining new subtypes of pectus excavatum and then its optimum surgical treatment options for the first time in the literature. Although we have some patients with deep asymmetrical deformities, we need further studies to compare results in a higher volume of patients from different centers all over the world. Thus, we plan to conduct a continuation study, after recognization of these new subtypes of the deformity, including different centers all over the world.

Addition to this; performing the wrong MIRPE technique which leads to insufficient or unsatisfactory results may necessitate correction with re-do surgeries which is riskier and complicative compared to non-redo cases. Recurrence rates for both Ravitch Sternoplasty and MIRPE vary from 2 to 37% in different series and publications [12, 24, 25]. In our series, we did not experience any recurrence including the ones who had undergone the removal of the bars.

Conclusion

It must be kept in mind that it is not always possible to repair all PE deformities with one type of MIRPE. Thus, every patient must be assessed carefully for identifying the subtype and optimum surgical technique. Our study is the first report in the literature describing well-defined subtypes of PE deformities and crossed bar technique can be performed safely for their correction with satisfactory results.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11748-023-01940-9.

Funding None declared.

Declarations

Conflict of interest None declared.

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