

## Do Nuss bars compromise the blood flow of the internal mammary arteries?

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### Abstract

**OBJECTIVES:** Minimally invasive repair of pectus excavatum, the so-called Nuss procedure, has become a popular technique in recent years. The internal mammary arteries (IMAs) lie on the posterolateral surface of the sternum, and the Nuss bar is likely to obstruct the blood flow in these arteries. This obstruction could become important in the later stages of the lives of these young people if they were to require coronary artery bypass grafting. The goal of this study is to investigate the extent of obstruction of the IMAs caused by Nuss bars.

**METHODS:** Data were collected prospectively on all patients who underwent the Nuss procedure between October 2011 and May 2012. Patients with a history of pectus excavatum repair by open surgery and those who were younger than 16 years of age were excluded. Computed tomography–angiography (CTA) was performed for the detection of IMA blood flow preoperatively and on the 10th post-operative day. Blood flow in the IMAs was evaluated blindly by two radiologists and classified as blood flow unaffected (group I) or affected (group II) by comparing the assessment of preoperative and postoperative CTAs. The patients in group II were also categorized as having blood flow obstructed bilaterally, blood flow obstructed unilaterally and others (diminished unilaterally/diminished on one side or obstructed on the other side).

**RESULTS:** Thirty-four patients (31 male and three female; mean age  $20.7 \pm 4.2$  years) underwent surgery. Blood flow was affected in 15 patients (44%), with bilateral obstruction in five, unilateral obstruction in seven, and unilateral diminished flow in two patients. In one patient, blood flow was diminished on one side and obstructed on the other. There was no significant difference between unaffected group I patients and affected group II patients in terms of sex, age, type of deformity, Haller index and the number of bars placed.

**CONCLUSIONS:** Nuss bars cause pressure on the IMAs, but a risk factor for this effect could not be identified. This is a relatively common clinical consequence of minimally invasive repair of pectus excavatum, and the long-term effects will be apparent following bar removal.

**Keywords:** Pectus excavatum • Chest wall deformity • Minimally invasive procedure • Internal mammary artery • Angiography

### INTRODUCTION

Pectus excavatum is the most common deformity among the congenital chest wall deformities, occurring in one in 300–400 live births. In pectus excavatum, there is an inward displacement of the sternum and the adjacent costal cartilages, although manubrium and first two ribs are in their normal position [1, 2].

The classical operation to correct pectus excavatum is the Ravitch sternoplasty [3]. In recent years, minimally invasive repair of pectus excavatum, the Nuss procedure, has become the most widely used technique. This technique is based on the placement of a shaped metal bar retrosternally for a certain period of time, with removal of the Nuss bar after remodelling of the anterior chest wall has been brought about by the continuous pressure maintained by the bar. Up to three bars can be placed for correction of the deformity.

The internal mammary artery (IMA) arises from the inferior surface of the first part of the subclavian artery in the root of the neck, at the medial border of the scalenus anterior muscle. It descends into the thorax posterior to the clavicle and the first costal cartilage. It passes inferiorly in the thorax, posterior to the superior six costal cartilages, about 1 cm from the margin of the sternum. It ends in the sixth intercostal space by dividing into the superior epigastric and musculophrenic arteries [4]. We have recently reported that the Nuss procedure had an 18.7% complication rate concerning both surgery and anaesthesia [5]. In addition to peri-operative complications, the Nuss procedure may have long-term effects. In patients who have had the Nuss procedure, the retrosternal bars are likely to compress the IMAs and obstruct the blood flow. This study was performed to investigate the effect of the Nuss procedure on the IMA blood flow. As IMAs are the most common arteries to be used as grafts during coronary artery

bypass surgery, it may be important to know whether the IMAs are obstructed or not in those young patients.

## MATERIALS AND METHODS

This prospective study was performed between October 2011 and May 2012 at our institution, with Local Ethics Committee approval and written informed consent of the patients. Thirty-four patients who had been admitted to our clinic for the Nuss procedure were included in this study. Patients who had any recurrent deformity following prior open surgery for pectus excavatum or who were younger than 16 years of age were excluded.

Routine preoperative evaluation consisted of postero-anterior and lateral chest X-rays, complete blood count, respiratory function tests and electrocardiography. In addition, computed tomography-angiography (CTA) of the thorax was performed in all patients to evaluate the internal mammary artery blood flow preoperatively. All computerized tomography (CT) scans were performed with a CTA protocol that involved administration of intravenous contrast media on a multidetector CT scanner (SOMATOM Definition Flash; Siemens, Munich, Germany). These preoperative CTAs were interpreted blindly by two radiologists. Those patients who did not have any preoperative IMA pathologies were included in the study and operated on with the Nuss procedure.

Our surgical technique for the Nuss procedure has been reported elsewhere [5, 6]. In brief, two transverse incisions were made on both sides, at the anterior axillary line. Subcutaneous tunnels were created bilaterally by blunt dissection reaching the highest points of the deformity. Meanwhile, the chosen template was shaped on the chest, and the bar was bent to match the template. A Nuss bar and stabilizer from TASARIMMED® Medical Devices Manufacturing and Marketing Inc. (Istanbul, Turkey) were used in all patients. A separate 1-cm incision was made at the right midaxillary line to place the thoracoscope. The videothoracoscope was inserted to explore the pleural cavity for the deepest point of the deformity and for any pleural adhesions. The introducer was inserted through the right incision and forwarded to the deepest point of the deformity to create a tunnel between the sternum and the pericardium. When the retrosternal tunnel had been created, the introducer was pushed through the left incision. Tape was tied to the eyelet of the introducer and pulled back, guiding the tape through the right thoracic cavity and out of the right incision. The bent bar was tied to the tape and pulled through the tunnel from right to left, with the convex side facing down. The bar was rotated through 180°, pushing the sternum upwards. In most cases, one stabilizer was placed on the left side as close as possible to the exit point from the thoracic cavity to avoid rotation. The bar and the stabilizer were secured on the muscles by sutures. Then the sternum was elevated. Intravenous patient-controlled analgesia was used in every patient.

The control CTA of the thorax was performed on the 10th postoperative day. These control CTAs were interpreted by the same radiologists. The effect of the Nuss bars on the internal mammary artery blood flow was evaluated by comparing pre- and postoperative angiographic findings. The diameters of the IMAs distal to the bars were compared in these angiographic studies. When diameters of the IMAs were smaller in the postoperative angiographic studies they were accepted as 'diminished', and when IMA lumens were invisible they were accepted as 'obstructed'. Patients were classified as a blood flow unaffected group (group I) and blood flow affected group (group II) according to the results of the

control CTAs. The patients in group II were also subclassified as having the IMA blood flow obstructed bilaterally, obstructed unilaterally and others (diminished unilaterally/diminished on one side, obstructed on the other side). Patients were also evaluated according to sex, age, type of deformity, Haller index and the number of Nuss bars inserted.

We have shown that minimally invasive repair of pectus carinatum deformity has a positive impact on both psychosocial and physical functioning of the patient [7]. Since then, we have adapted and used the same 'modified Nuss questionnaire' for patients who are undergoing the Nuss procedure for pectus excavatum deformity [7]. The questionnaire was administered to all patients preoperatively and during the 6th postoperative month to assess the quality of life and satisfaction of the patients.

## Statistical analysis

SPSS for Windows software (version 17.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Pearson's chi-squared test was used for comparing categorical data, and Student's unpaired *t*-test was used for the comparison of continuous data. One-way ANOVA was performed to compare continuous data in the subgroups within group II. The weighted Kappa test was used for comparing the interpretations of the two radiologists of the CTAs results. Values of  $P < 0.05$  were regarded as statistically significant. Continuous data are presented as means  $\pm$  SD and categorical data as frequencies and percentages while presenting descriptive statistics.

## RESULTS

Thirty-one of 34 patients were male. The mean age of the patients was  $20.7 \pm 4.2$  years (range, 16–30 years). Table 1 shows the patients' characteristics with regard to sex, age, type of deformity, Haller index, number of bars, bar size and postoperative blood flow in the IMAs.

The mean operation time was 79 min (range, 50–120 min) and the mean length of hospital stay was 4.7 days (range, 3–7 days). Postoperatively, pneumothorax was detected in one patient (group I) as a complication and treated with a chest tube. Patients' satisfactions were 96% according to the modified Nuss questionnaire.

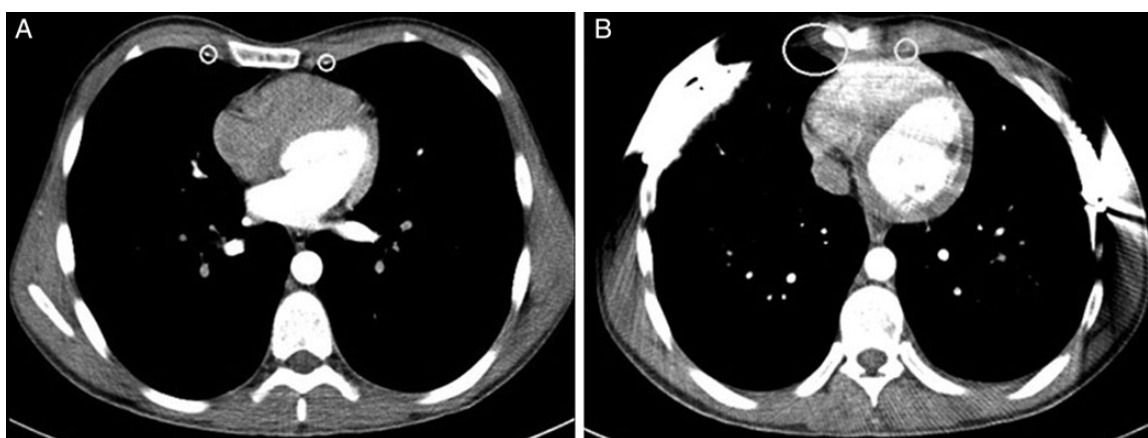
Blood flow of IMAs was unaffected in 19 patients (56%) according to postoperative CTA results, while it was affected in 15 patients (44%). The Kappa inter-rater agreement coefficient was 0.76 between the two radiologists. We have identified four distinct patterns of effect of Nuss bars on IMAs, namely: bilateral obstruction; unilateral obstruction; unilateral diminished flow; and diminished flow on one side and obstructed on the other side (Fig. 1). Comparisons between group I and group II with regard to the number of patients, sex, age, type of deformity, Haller index and number of bars is shown on Table 2. In group II patients, bilateral obstruction of blood flow was detected in five patients, unilateral obstruction in seven patients and unilateral diminished flow in two patients. In addition, in one patient obstruction of the blood flow was detected on one side (right) with diminished flow on the other side (left).

There was no significant difference between group I and group II regarding the sex, age, type of deformity, Haller index and number of pectus bars (Table 2).

The patients in group II were subclassified as a bilaterally obstructed group, a unilaterally obstructed group and others.

**Table 1:** Characteristics of the patients

Patient no. (n = 34)	Sex (M/F)	Age (years) (20.7 ± 4.2)	Deformity (S/A)	Haller index (3.53 ± 1.03)	Number of bars	Bar size (mm)	Postoperative blood flow
1	Male	23	Symmetric	4.22	2	310 + 330	Unaffected
2	Male	16	Asymmetric	2.98	2	234 + 250	Unaffected
3	Female	18	Symmetric	4.01	1	280	Affected
4	Male	29	Symmetric	4.22	2	355 + 375	Affected
5	Male	17	Symmetric	3.47	2	280 + 320	Affected
6	Male	26	Symmetric	4.31	2	330 + 355	Affected
7	Male	19	Symmetric	3.95	2	288 + 320	Affected
8	Male	17	Asymmetric	2.48	1	305	Unaffected
9	Male	26	Symmetric	2.55	2	288 + 288	Unaffected
10	Male	24	Symmetric	3.38	2	330 + 355	Affected
11	Male	21	Symmetric	3.04	2	305 + 320	Unaffected
12	Male	17	Symmetric	3.53	2	330 + 355	Unaffected
13	Male	17	Symmetric	2.81	2	310 + 330	Affected
14	Female	20	Asymmetric	2.35	2	260 + 330	Unaffected
15	Male	19	Asymmetric	2.08	1	330	Affected
16	Male	20	Symmetric	4.08	2	320 + 320	Affected
17	Male	25	Symmetric	3.34	1	375	Unaffected
18	Male	19	Symmetric	4.73	2	330 + 355	Unaffected
19	Male	17	Asymmetric	4.77	2	330 + 355	Affected
20	Male	18	Symmetric	7.14	2	310 + 320	Unaffected
21	Male	16	Symmetric	2.82	1	320	Unaffected
22	Male	30	Asymmetric	2.96	2	355 + 375	Unaffected
23	Male	27	Symmetric	3.52	1	355	Affected
24	Male	22	Symmetric	3.04	1	355	Affected
25	Male	17	Asymmetric	2.95	2	305 + 330	Unaffected
26	Female	16	Symmetric	3.34	1	305	Unaffected
27	Male	19	Symmetric	2.24	2	310 + 320	Affected
28	Male	22	Symmetric	5.21	1	355	Unaffected
29	Male	29	Symmetric	4.58	1	320	Unaffected
30	Male	25	Symmetric	2.46	1	320	Unaffected
31	Male	19	Symmetric	2.44	1	305	Affected
32	Male	17	Asymmetric	3.02	1	305	Unaffected
33	Male	19	Symmetric	4.01	2	355 + 375	Unaffected
34	Male	17	Symmetric	4.03	1	320	Affected

**Figure 1:** Diminished blood flow in the internal mammary arteries on one side (left) and obstruction on the other side (right). (A) Preoperative. (B) Postoperative.

Characteristics of the patients in these subgroups of group II are shown and compared in Table 3.

There was no significant difference between the subgroups of group II with regard to sex, age, type of deformity, Haller index and number of pectus bars (Table 3). As no adverse clinical outcome was observed in our patients, it was not possible to correlate the blood flow with any adverse clinical outcome as an objective marker.

## DISCUSSION

Minimally invasive repair of pectus excavatum using the Nuss procedure has become a procedure of choice in many institutions worldwide. Although it is a safe and successful method, some complications regarding the Nuss procedure are not uncommon [5, 8–10]. Recently, we have reported our complication rate to

**Table 2:** Comparison of the two groups with regard to number of patients, sex, age, type of deformity, Haller index and number of bars

	Group I (blood flow unaffected; n = 19)	Group II (blood flow affected; n = 15)	P-value
Male	17	14	0.69 <sup>a</sup>
Female	2	1	
Mean age ± SD (years)	20.7 ± 4.5	20.6 ± 4.0	0.99 <sup>b</sup>
Deformity symmetric	13	13	0.26 <sup>a</sup>
Deformity asymmetric	6	2	
Haller index ± SD	3.6 ± 1.2	3.5 ± 0.8	0.84 <sup>b</sup>
Single bar	8	6	0.90 <sup>a</sup>
Two bars	11	9	

<sup>a</sup>Pearson's chi-square.<sup>b</sup>Student's unpaired t-test.

be 18.7% [5]. Park and colleagues [8] had a complication rate of 16%, and in a European multicentre study [9] a complication rate of 19% was reported. Hebra *et al.* [10] reported negligible mortality and an overall morbidity rate of ~15%, with bar displacement and pneumothorax accounting for the vast majority of the complications. In a review of 19 reports of 1949 children who underwent the minimally invasive repair of pectus excavatum over a 20-year period, no mortality was observed and the morbidity was 15.4% [11]. Breakage of the wires used to secure the lateral stabilizer, pleural effusion, intraoperative rupture of the intercostal muscles, pericardial tears without clinical significance and atelectasis were also reported as some minor early complications [12]. Even though most of the complications are minor, some major complications, such as mediastinitis, sternal fractures, sternoclavicular dislocations, pericarditis, aortic injury, cardiac perforation, acute occlusion of the inferior vena cava, fatal arrhythmia, diaphragmatic hernia, penetrating injury to abdominal structures and erosion of a pectus bar through the sternum, were also reported [5, 10, 13–20]. Nowadays, most of these complications can be prevented or minimized with increasing experience and advances in the minimally invasive technique.

As stainless-steel Nuss bars are placed behind the sternum, with the guidance of thoracoscopy, to keep the sternum in the desired position by lifting it, and as the internal mammary arteries lie on the posterolateral surface of the sternum bilaterally, these bars are likely to block the blood flow in patients who have had the Nuss procedure.

Although there are many reports about the early, late, minor and major complications of the Nuss procedure, no previous research has been reported in the literature about the effect of the Nuss bars on the IMAs. In the present study, we have observed that the Nuss bars were creating pressure on the IMAs in 44% of our patients. However, no significant risk factor was determined to explain the obstruction by the Nuss bars of the blood flow in the IMAs.

It is well known that the multidetector CT scanner enables accurate and non-invasive visualization of vessel anatomy, flow and patency and is a reliable method for examining coronary arteries and bypass grafts [21–23]. In the present study, we also agree with

**Table 3:** Characteristics of patients in subcategories of group II

	Blood flow of internal mammary arteries			P-value
	Bilaterally blocked (n = 5)	Unilaterally blocked (n = 7)	Other (n = 3)	
Male	5	7	2	0.12 <sup>a</sup>
Female	0	0	1	
Mean age ± SD (years)	19.9 ± 2.6	20.7 ± 4.3	22.0 ± 6.0	0.78 <sup>b</sup>
Deformity symmetric	5	6	2	0.40 <sup>a</sup>
Deformity asymmetric	0	1	1	
Haller index ± SD	3.1 ± 0.8	3.8 ± 0.7	3.4 ± 1.2	0.42 <sup>b</sup>
Single bar	1	3	2	0.42 <sup>a</sup>
Two bars	4	4	1	

<sup>a</sup>Pearson's chi-squared test.<sup>b</sup>One-way ANOVA.

the others that the multidetector CT scanner is a fast imaging modality that can be used in conjunction with chest CT to evaluate the IMAs along with the thoracic cavity [21–23].

In conclusion, our preliminary results showed that retrosternal placement of the Nuss bars may affect the blood flow in the internal mammary arteries in up to 44% of the patients who underwent the Nuss procedure. However, no risk factor was identified, and the clinical consequences of this obstruction are unknown. We suggest that there is a need for further studies with larger groups of patients to identify the risk factor or factors that affect the blood flow in the IMAs. A new prospective study has been designed to assess whether this obstruction is reversible or not following bar removal.

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**Conflict of interest:** none declared.

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#### eComment. Nuss pectus excavatum repair: friend or foe?

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In their recent article, Yüksel and coworkers conducted a prospective study of the internal thoracic artery (ITA) blood flow after placement of Nuss bar for the treatment of pectus excavatum (PEX). Yüksel and coworkers clearly demonstrated that the blood flow of these arteries is affected in 44% and 38% of patients with complete unilateral and bilateral obstruction, respectively [1]. Since ITAs are widely used for coronary bypass grafting, a history of PEX Nuss repair could impede the potential use of the ITA for coronary revascularization in the long term. We congratulate the authors for this interesting description of an unexpected effect of the Nuss procedure. In fact, other types of ITA lesions have already been reported following this technique. Besides perioperative injuries requiring emergent thoracotomy (2 cases in the English literature), Nuss bar pressure on the undersurface of the anterior chest wall or bar dislocation may result in:

1. ITA pseudoaneurysm treated successfully with selective embolization with coils [2];
2. ITA rupture into the pleural cavity and consecutive life-threatening haemothorax requiring emergent thoracotomy or angiographic embolization [3–5].

In contrast, during the Ravitch-type PEX repair, the careful subperichondrial resection of elongated cartilages protects the internal thoracic vessels from perioperative damage. Furthermore, no delayed ITA lesions have been described in the literature following this procedure. In the discussion, Yüksel and coworkers list minor and severe complications associated with the Nuss repair [1]. Some of them are impressive, rendering the safety of the method questionable, in addition with the above-mentioned ITA injuries. Finally, the relevant article by Yüksel and coworkers describing an unexpected adverse effect of the Nuss repair validates our previous option of correcting PEX deformities exclusively by means of a simplified Ravitch-type technique.

**Conflict of interest:** none declared

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