**Background/Purpose:** Thoracoscopic Nuss repair of funnel chest is gaining increasing acceptance among pediatric surgeons. The classic Nuss repair, however, has a considerable complication rate of 21% to 67%, and reoperation rate of 29%. Although no lethality has been reported, 5% to 24% of bar or stabilizer dislocations, stabilizer fractures, and problems in soft tissue coverage are a challenge apart from reported cardiac, aortic and hepatic injuries. Molik et al reported a mean age of 12.6 years for the standard procedure and 9.5 years for Nuss patients, whereas Miller et al communicated a mean age of 11.5 years, Engum et al had a mean age of 8.2 years (range, 5 to 15), and Nuss et al reported a range of 15 months to 15 years in his original publication. This indicates an obvious selection of favorable patients in preschool and early school age, who technically are easier to correct, but are more likely to have recurrences during the growth spurt in puberty as we observed in our conventional patients.

Consequently, we decided to perform thoracoscopic funnel chest repair on patients in the same age group as those in the open repair, i.e., 12 to 18 years or during and toward the end of puberty. We intend to leave the bars in situ beyond the termination of growth if possible. However, in the first 2 Nuss patients (16 and 15 years of age) we realized that bar fixation became much more of a challenge in sturdy and physically active adolescents, and we did not want to restrict their normal and sports activities. Therefore, we introduced several technical modifications to the original Nuss technique with the aim of reducing the incidence of bar dislocation or latent bar instability and used 2 stabilizers on principle.

**MATERIALS AND METHODS**

From April 2000 to December 2001, 42 adolescents and young adults (38 boys and 4 girls) with severe pectus excavatum (Haller index of 3.4 to 5.8) underwent Nuss repair with bilateral thoracoscopic assistance, 40 by the modified procedure described below, on which this study focusses. The patients ranged in age from 12.3 to 42.1 years with an average of 17.6 years (median, 16.1 years), and all patients underwent follow-up to date in a prospective observation study. All patients were symptomatic preoperatively; the most common complaints were shortness of breath on prolonged exertion, sensations of a heavy weight on the chest or chest pain, sensations of a noticeable heart beat even on slight exertion, and frequent bronchopulmonary infections. All the patients felt significantly impaired in sports and social activities. Twenty-six (65% 26 of 40) patients had thoracic asymmetry, and 17 (42.5% 17 of 40) showed some degree of sternal rotation in addition.

For the modified Nuss repair we used a HDTV monitor plus a second monitor, 30° 5-mm lens for bilateral thoracoscopy, which was very helpful for retrosternal dissection in extremely deep funnels, and the following modifications of the standard Nuss procedure:

1. Thoracic...
muscles are dissected off the ribs by diathermy to provide ample muscle pockets. (2) Bars ends plus stabilizers are placed into the submuscular pockets directly on the ribs. (3) The bars are fixed to adjacent ribs by pericostal sutures under thoracoscopic assistance. (4) Stabilizers are jammed on the bent bar by a bone hammer and fixed without wires. (5) Bars and stabilizers receive pericostal figure of 8 fixation through their end holes. (6) For severe funnels greater than 16 years a second bar is inserted through the same incisions. (7) First bars are fixed by 14 to 18 absorbable pericostal sutures and second bars by 6 to 10. (Bars by Walter Lorenz Surgical, Jacksonville, FL.)

In addition, 11 patients had costal arches corrected by single or serial subtotal rib osteotomies from the Nuss accesses. Fifteen of 40 patients (37.5%) had 2 bars inserted, and all patients had 2 stabilizers (Fig 1). The second bar usually is 2 inches shorter to avoid crowding of the bars and stabilizers, is introduced without stabilizers, and fixed by 6 to 10 pericostal figure of 8 sutures with pericostal fixation to the end holes of the first bar and its stabilizers. With 2 bars, the rotational stress on each bar is halved owing to distribution of sternal pressure between the 2 bars so that the second bar may be shorter, which facilitates introduction and fixation through the same skin access.

All patients except 4 received an epidural catheter for perioperative patient-controlled analgesia (PCA) for 5 days without any complication, which made half the patients pain free. All patients were monitored postoperatively on an observation ward, because 3 overdosages of epidurals were reported.2,11

Average operating time was 2.1 ± 0.8 hours with the longest times in older patients and double bar fixation. The length of follow-up was 3 to 22 months (average, 9 months), and all children underwent regular follow-up at 3 monthly intervals before and will undergo follow-up at yearly intervals after bar removal up to 5 years postoperatively (the same protocol we use in conventional repairs).

RESULTS

All operations were completed as Nuss repairs, and there was no conversion to a Hegeman Willital, our standard open procedure.8 Thirteen patients required a second bar, predominantly at older ages, deep funnels, or marked sternal torsions. Whereas Nuss inserted the second bar through separate incisions,7 we inserted all double bars through the same 4 to 6-cm incision, whereas a single bar incision would be about 2.5 cm. With our modifications there was not a single bar or stabilizer dislocation.

The postoperative course was uncomplicated in all patients except 3: one patient had seroma near the un-

DISCUSSION

Our overall complication rate of 7.5% (3 of 40) for the modified Nuss procedure is low compared with the 21% to 67% reported in the literature.1-3 There was one trauma-induced seroma probably not directly related to the procedure, one pleural, and one pericardial effusion. Pericarditis with pericardial effusion is a rare incidence, which probably can not be influenced by operative technique, but one case has been reported in both the European (1 of 165, 0.6%) and the American multicenter study (1 of 251, 0.4%) and in Miller’s series, in addition to our case.1-4,5

The mean follow-up of 9 months (range, 3 to 22) in our preliminary experience is very short, but long enough to comment on bar dislocation, which is reported universally to be an early complication of the first 30 postoperative days (range, 5 to 60).2-4 The reduction of bar and stabilizer dislocation to zero in our series, despite allowing all sports activities 6 weeks postoperatively and despite exclusion of the more favorable patients below 12 years, seems to indicate a definite improvement of both the results and the quality of life for patients undergoing the modified Nuss procedure. Considering that under these conditions a higher bar dislocation should be expected, our results compare favorably with the reported incidence of 5% to 24% bar and stabilizer dislocation in other studies.1-5

In our opinion, it is virtually impossible to “secure” bars to the chest wall muscles as Hebra et al4 pointed out after Nuss’s original description. Even if “several mattress sutures are used to pull the tissue across the bar,” it is not going to work reliably, particularly in older patients, who require longer bars that act as more effective levers and exert stronger rotational momentums on an intrinsically weak fixation of a bar, that is not firmly attached to the bony thorax itself, where it should be fixed. As the basic problem with bar fixation was realized increasingly, bar stabilizers were recommended by many investigators, but were not used in a standardized man-
ner, whereas we use at least 2 bar stabilizers in every patient. The next question is, how should stabilizers be fixed to the bars, because stabilizer displacement has been a frequent occurrence. Although a wire suture around bar and stabilizer is recommended by the bar producer, we never have used wire sutures for Nuss stabilizer fixation and have not observed a single stabilizer dislocation. Instead, we bent the end of the bar slightly too much and jammed the stabilizer to the bar by several good blows of a heavy bone hammer before bar rotation. In addition, we used multiple pericostal sutures as described above (Fig 2).

A recent series by Miller et al\(^5\) reports a 5% bar displacement rate (5 of 80) and recommends the routine use of stabilizers. They report isolated fractures of individual stabilizers, which seem to indicate latent instability. Moreover, they restricted many sports in their patients and had a substantial number of patients below 12 years who are probably at low risk for bar displacement. Unfortunately, they do not comment on the age of their 4 bar displacements, but if they belong to the older-than-15-year group as Hebra et al\(^4\) reported, 4 of 23 (17.4%) would correspond to the figures reported in the literature. Both Nuss and Coran\(^2\) realized, that stabilizers alone do not exclude bar dislocation and reported on the use of an occasional, single pericostal suture/wire in an older patient.\(^2,7\) Hebra et al\(^10\) recommended one thoracoscopically placed nonabsorbable pericostal suture and got a bar dislocation rate of 5% (1 of 20) in a series of 20 patients aged 14 on average, but pericostal sutures with subcutaneous bars risk muscle necrosis between bar and rib, as we observed before adopting submuscular bar position, which eliminates bar pressure on the muscle. Hebra himself assumed that additional fixations might be necessary in older and active patients, but obviously had no experience of his own in this age group. In our own series of 902 thoracic deformities corrected conventionally during a 14-year period (1984 through 1997) before introducing the Nuss technique we have shifted from correcting younger children to late school age and ceased to operate on children below the age of 10 after 1990.\(^8\)

When we tried the original Nuss epifascial bar fixation in our first 15- and 16-year-old patients, the muscle between bar and bony thorax became necrotic, resulting in prolonged seroma, which eventually necessitated removal of the first bar after one year. With this experience in our first 2 patients we felt strongly that all these propositions are helpless attempts to stabilize an intrinsically unstable bar lying in the wrong position, ie, subcutaneously on the fascia.

To achieve a fundamental improvement, the bar needs to be put one layer deeper, ie, into a submuscular pocket directly on the bony thorax. Then, the logical consequence is not to fix the bar to an occasional adjacent rib, but the most stable situation results if a long bar is chosen and is fixed to every rib it crosses by strong pericostal sutures, which are introduced under thoracoscopic vision on both sides (Fig 3). Usually 4 to 6 heavy pericostal

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**Fig 2.** View of the right bar end (B) positioned in an epicostal position below the lateral serratus muscle in a pocket directly on the ribs and intercostal spaces. The situs shows the lateral 4 (of 6 pericostal figure of 8 sutures (1, 2, 3, and 4) of braided PDS (1) fixing the bar (B) and stabilizer (S) to the ribs it crosses.

**Fig 3.** Thoracoscopic view of a strong needle (n) passing from outside around the rib and leaving the thorax through the next intercostal space (i). The right lung (rL) is kept well out of the way by the inflated pneumothorax (CO\(_2\), 8 mm of mercury).
figure of 8 sutures fix each bar on every side of the patient. Moreover, the end holes of the bar and of both stabilizers are fixed by pericostal figure of 8 sutures through the holes, which adds 3 additional pericostal sutures per bar on each side (Fig 4). Finally, the basic idea of Hebra et al\textsuperscript{10} is correct, that the fulcrums of rotation are the points at which the bars enter the thorax, because these are the only regions, where the bar cannot shift, whereas the ends of the bar and the sternal region of the bar may move. Therefore, a fixation close to these entry points gives the maximum protection against bar rotation. Therefore, we fix the bar not only to all ribs on which it rests, but we place an additional figure of 8 pericostal suture medially so that the bar also is suspended to the first rib it supports. We found that absorbable sutures like Vicryl or braided PDS are perfectly satisfactory for bar fixation. Nonabsorbable sutures or wires may cause local problems, and additional parasternal sutures or subxiphoid incisions may cause unsightly hypertrophic scars in an aesthetically important region, whereas our fixation used the 2 small lateral accesses. Molik et al\textsuperscript{2} discouraged the routine use of stabilizers, because they appeared very prominent on the chest walls of their younger patients, and, likewise, the bar is visible laterally in Miller's illustration,\textsuperscript{5} whereas in the submuscular position, bars and stabilizers are much better covered and, thus, virtually invisible (Fig 5).

![Fig 4. View of the right bar end (B) positioned deep to the muscle pocket (m) directly on the ribs and intercostal spaces. The situs shows the bar and stabilizer being fixed by pericostal figure of 8 sutures (1 and 3) through the holes and fixing the bar to the rib (2).](image)

![Fig 5. 16-year-old patient with a nearly symmetric funnel chest (left) treated by modified Nuss repair (right, after one year with single bar and 2 stabilizers in place). Multiple pericostal bar fixation was possible from the inconspicuous 2.7 cm lateral access with excellent result, because bars and stabilizers are virtually invisible in a submuscular position.](image)
With the original Nuss technique resulting in recurrent wound seromas and muscle necrosis between bar and ribs (50% bar dislocation rate in the first 2, we changed the technique fundamentally after these 2 patients. Admittedly, we made these modifications very early in our learning curve but could rely on a vast experience of conventional funnel chest repairs\(^8\) and later needed no further modifications, although we were urged by progressively older patients to offer them the Nuss technique as well. This is no problem in Germany because funnel chest is considered a congenital malformation and treated by pediatric surgeons regardless of age. For the next 40 patients we used the submuscular epicostal bar position and absorbable pericostal bar fixations with no bar dislocation, no wound infection, and no incidence of persistent postoperative pain. Moreover, unlike most other investigators we do not restrict the activity of our patients at all; they are allowed to go swimming from the third postoperative week and do whatever does not cause pain from the sixth week. One of our patients restarted regular competitive football 5 times a week in his sport club 3 weeks after discharge from the hospital with no adverse effect for the past 1 1/2 years. When we removed the first bar inserted by the modified Nuss technique after 13 months, we found the stabilizers well fixed, partly lined by small bony ridges, and surrounded by a firm sheath of connective tissue, and all pericostal sutures had been absorbed. However, bar removal was no problem, and the bar was easy to pull out in lateral decubitus position after the stabilizers had been freed. Moreover, we know from our conventional experience\(^8\) that removal of submuscular bars with pericostal fixation is no more difficult after one year than after 4 years.

With a mean of 17.6 years ± 5.8 years (median, 16.1 years) our Nuss patients are nearly double the age as in most series reported so far. Even though this age group is notorious for increased operating times and complications,\(^4,5\) and we do not restrict the sportive activity at all, with our modified technique the incidence of stabilizer dislocation and bar displacement has been zero so far, although this series includes most of our learning curve. However, the technique is technically more demanding and increases operative time by half an hour.

Taking into account the limited and early experience, we could prove the modified Nuss technique to be safe even for a higher age group in a sizeable series of adolescents (35 patients > 15 years as opposed to 23 in Miller’s series\(^5\)). Hence, despite the more difficult patients, the most frequent complication could be reduced well below all previous reports, if not eliminated, by the described modifications of the original Nuss technique. At the same time, the patient comfort is high, and the aesthetic results are excellent, which should warrant further evaluation of this technique by other centers.

REFERENCES