Is a Shorter Bar an Effective Solution to Avoid Bar Dislocation in a Nuss Procedure?

Marco Ghionzoli, MD, PhD, Gastone Ciuti, PhD,* Leonardo Ricotti, PhD,* Francesca Tocchioni, MD, Roberto Lo Piccolo, MD, Arianna Menciassi, PhD, and Antonio Messineo, MD

Department of Pediatric Surgery, Children's Hospital A. Meyer, Florence, Italy; The BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera, Italy

Background. **A variety of expedients to minimize bar dislocation in the Nuss procedure has been reported. The aims of this study were to create a mathematical model to define mechanical stresses acting on bars of different lengths in the Nuss procedure, and to apply this model to clinical scenarios.**

Methods. **Finite element model analyses were used to outline the mechanical stresses and to mathematically define different cases. Data from a group of patients with procedures carried out using standard Nuss criteria (NC group; bars half an inch shorter than the distance between the mid-axillary lines) were compared with data from a second group treated by applying model-based suggestions (MS group; bars approximately 3 inches shorter than the distance between the mid-axillary lines).**

Results. **Mean patient age in the NC group (48 cases) was 16.4 years old (84% males). The mean operating time was 57 minutes, and the mean bar length was 14.19 inches. There were 5 cases (10.4%) of bar dislocation. Mean patient age in the MS group (88 cases) was 16.2 years old (87% males). The mean operating time was 43 minutes and the mean bar length was 11.67 inches. There was only 1 bar dislocation, a reduction from 10.4% (NC) to 1.1% (MS) odds ratio 0.0989 (confidence interval 0.0112 to 0.8727), $p = 0.0373$.**

Conclusions. **A shorter Nuss bar reduces tension on the sutures applied at bar extremities. This leads to enhanced bar stability and a reduced risk that the bar will flip. The use of a shorter Nuss bar may reduce the incidence of bar dislocation.**

(Ann Thorac Surg 2014;97:1022–8)

Pectus excavatum (PE) is the most common anterior chest wall deformity and is associated with cardiorespiratory and cosmetic problems. Until 2 decades ago, the most frequent operation in use for PE correction was the Ravitch procedure. This entailed complete removal of the abnormal cartilages while sparing the perichondrium, followed by sternal elevation and stabilization [1]. In 1998, Nuss and colleagues [2] described a minimally invasive technique for anterior chest wall remodeling, employing a metal bar and avoiding the need for cartilage resection. This approach was designed to enable improved functional and cosmetic outcomes. However, this technique is associated with a high risk of postoperative bar displacement, especially in the early postoperative period [3], due to an imbalance between the high rotational torque and a poor bar stabilization or fixation.

To date, several strategies have been described in order to minimize the risk of bar dislocation. Although a lateral stabilizer is not always necessary for the prevention of bar displacement in younger patients whose ribs and rib cartilage are still soft [4], lateral alloy stabilizers were proved popular [5, 6]. A variety of bar fixation techniques have also been suggested [7–9]. These methods have contributed to a reduction in the incidence of bar displacement. However, there is still a significant risk of complications (hemothorax and pneumothorax) due to the procedure itself. Notwithstanding the accrued experience of the past decade, bar dislodgement still occurs in around 5% of cases [10].

To date, there are no reports on the effects of bar length on the incidence of bar dislocation. We developed a model to improve understanding of the mechanism underlying bar dislocation, considering both forces and torques acting on the bar and the correspondent mechanical constraints, and focusing in particular on bar length. In order to outline the mechanical forces acting on bars of different lengths, we generated a computer-assisted design (CAD) model coupled with a finite element model (FEM)-based mechanical simulation. We then applied the outcomes of the model to a prospective case series and compared the surgical outcome of this new group with our historical surgical series.

Accepted for publication Nov 11, 2013.

*Drs Ciuti and Ricotti contributed equally to this work.

Address correspondence to Prof Messineo, Department of Pediatric Surgery, Children's Hospital A. Meyer, Viale Pieraccini 24, 50100 - Firenze, Italy; e-mail: a.messineo@meyer.it.

The Appendix can be viewed in the online version of this article [http://dx.doi.org/10.1016/j.athoracsur.2013.11.037] on http://www.annalsthoracicsurgery.org.

Published by Elsevier Inc

0003-4975/$36.00
http://dx.doi.org/10.1016/j.athoracsur.2013.11.037

Material and Methods

After Ethical Committee approval, we retrospectively reviewed the records from patients undergoing PE repair by the Nuss procedure between March 2006 and December 2009. All data related to hospital stay, rate of postoperative complications, and follow-up results were reviewed. This group of patients had standard procedures according to the Nuss criteria (NC, as described above).

Surgical Management

At our Pediatric Surgery Department the standard procedure is as follows: (1) when the patient is positioned at the operating table, the most depressed area of the sternal plate and determined points on both sides of the chest ridge of the patient are identified; (2) a 5-mm thoracoscope is inserted 2 intercostal spaces above the right incision site to verify the deepest point of sternal depression and to monitor the procedure; (3) 2 curved skin incisions of 3 to 4 cm in length are made at the midaxillary lines on both sides, and a subcutaneous tunnel is created up to the determined points on the chest ridge; (4) a metal introducer is inserted into the thorax at the determined point of the right chest ridge to dissect the plane separating the sternum from the pericardium; the introducer is exteriorized on the left side and pushed through the skin incision. A tie is tightly attached to both the introducer tip and the bar and the introducer is pulled backward, allowing the passage of the bar through the dissected plane. The bar is inserted with the concave side anterior; (5) the bar is rotated 180 degrees around its axis, thus pushing up the sternum. Stainless-steel stabilizers are routinely inserted on both sides of the bar, as close as possible to the bar end. These are secured with pins and are eventually fixed to intercostal muscles by interrupted polyglactin sutures. An additional bar is introduced if the cosmetic result is unacceptable with a single Nuss bar, and a single stabilizer per bar is placed on opposite sides. If pectus excavatum is asymmetrical, the bar is curved asymmetrically according to a previously described method [9]. All procedure-specific instruments are supplied by Medexpert, Eschbach, GmbH, Germany.

Postoperative pain is managed with epidural analgesia and nonsteroidal antiinflammatory drugs. The follow-up protocol included outpatient visits at 1 month and 6 months, and then annually for 3 years. Light physical activity was reintroduced a month after surgery, and more rigorous sports (except contact sports) were allowed after 6 months. The bar was removed after the 3-year follow-up period.

Chest x-rays were taken postoperatively in all patients to document the result of the procedure and to allow assessment of the position of the bar during the follow-up period. We classified "bar dislocation" as an altered, "flipped" position apparent on a lateral chest x-ray film. Bar dislocations were classified as mild (15 to 30 degree angle formed between the bar and the horizontal plane), moderate (angle between 30 and 60 degrees), or severe (beyond 60 degrees) (Fig 1).

Mechanical Model

We investigated the underlying mechanisms of "bar dislocation," generating a mechanical model that took into account both the forces and torques acting on the bar-stabilizer complex, and the correspondent mechanical constraints. In order to develop a model that included all the different cases we encountered in the clinical setting, we outlined 7 chest size configurations with increasing thoracic girth (A to G), to which corresponded 7 short and 7 long Nuss bar types (Appendix Fig 1). The CAD representations of these bars were developed. The FEM-based simulations were then performed to estimate the distribution of the physical stresses acting on the system. For CAD representations, engineering design-dedicated three-dimensional software was used (Pro/Engineer, or ProE, version no. 5.0; Parametric Technology Corporation, Needham, MA). For FEM analyses, a finite

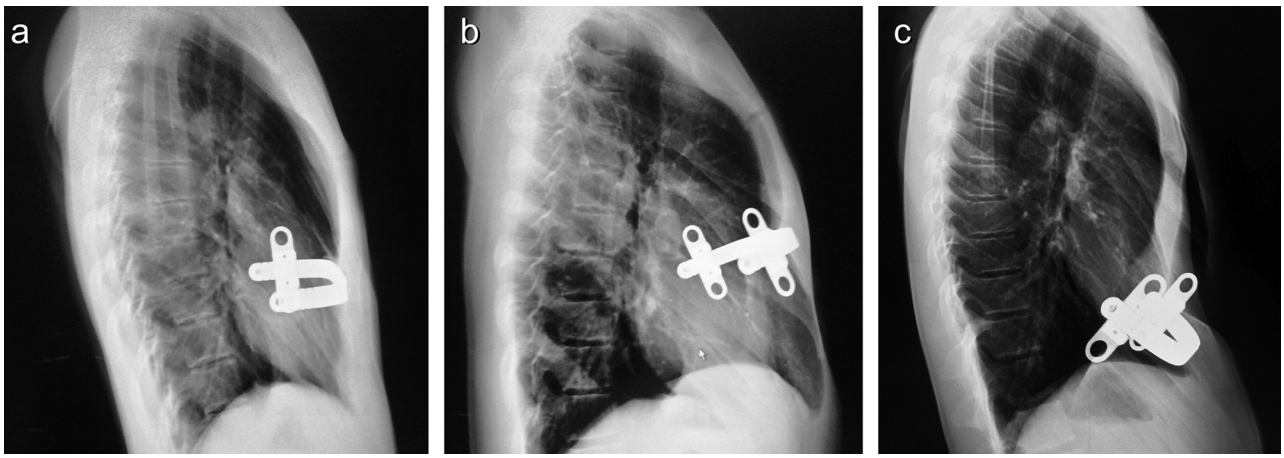

Fig 1. Postoperative lateral chest roentgenograms in 3 different patients: (a) patient with a Nuss bar in place: the angle formed by the bar with horizontal line is less than 15 degrees. (b) Patient with a Nuss bar mildly dislocated (angle between 15 and 30 degrees). (c) Patient with a Nuss bar moderately dislocated (angle between 30 and 60 degrees) which required an early bar removal.