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Case Report

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THE CONTRIBUTION OF 3D PRINTING IN THE MINIMALLY INVASIVE SURGERY OF PECTUS EXCAVATUM: A REPORT CASE OF THE FIRST EXPERIENCE OF A MOROCCAN CENTER

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ABSTRACT

Introduction: Pectus excavatum is a congenital deformity of the chest wall, seemingly related to abnormal cartilage growth in the costochondral region. Minimally invasive repair, as described by Donald Nuss, has become the gold standard therapeutic approach. This procedure relies on metallic bars of which the number, length and insertion site are adapted to each patient, following precise radiological data; the results depend heavily on the surgeon's experience. The authors report a case of the minimally invasive repair of pectus excavatum using 3D printing. **Report Case:** A 16 years old child, with a 2-year funnel chest deformity and a history of exertional dyspnoea and symptoms of clinical depression presented with an asymmetrical pectus excavatum of the lower sternum and a right sternal rotatory deviation. Spirometry showed a restrictive ventilatory defect. Digital simulation, using images from a computed tomography segmentation of the chest wall, allowed a tailored printing of the bars prototype to the length and shape required to correct the defect. The patient underwent a Nuss procedure using a crossed-bar system, with excellent clinical and esthetical outcomes. **Discussion:** The use of 3D printing in the Nuss procedure ensures better planning, through an early adjustment of the bars and a preoperative detection of both bar insertion and exit bar sites. 3D printing allowed us to repair the deformity using only two-bars implant. Following the conventional procedure would have required three parallel bars, thus cutting costs in a low-revenue country. **Conclusion:** The pre-operative 3D conception of the chest wall's deformity and the bar's measurements helps simulate and adequately plan the surgical procedure. Therefore, reducing surgical time and creating pedagogical support for surgeons training.

Keywords: Chest wall; 3D printing; Pectus excavatum; Morocco.

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INTRODUCTION

Pectus excavatum is a chest wall deformity with a prevalence of 1/300 - 1/1,000 and a sex ratio of 5:1 [1]. A minimally invasive procedure, described by Donald Nuss in 1997, revolutionized the surgical correction of the defect. It included the endoscopic retrosternal implant of metallic bars, passing through both hemothoraces; the bars are initially bent following the anterior chest wall and then flipped 180° with the convexity facing the posterior side of the sternum. Stabilizers on each extremity can ensure optimal fixation of the bars [2-4]. Many variants of this technique have been described [5-7]. The number and dimensions of the bars were determined preoperatively using the patient's measurements, radiological data and, sometimes, the surgeon's experience. Some cases, mainly complex and/or challenging ones, were based on trial and error following several insertion-and-reinsertion attempts [8-9]. To tackle this issue, the authors report the case of surgical correction of Pectus excavatum using the Nuss procedure and a 3D anatomical model of the deformity. The model provided a simulation of the procedure, the size, length and bending angles of the bars.

CASE REPORT

A 16 years old child, with a 2-year funnel chest deformity, presented with complaints of dyspnoea, depression, isolation tendencies and poor school attendance. Physical examination showed a low asymmetrical pectus excavatum with a right sternal rotation, kyphosis and costal flaring (**Figure 1**). Chest computed tomography (CT) confirmed the asymmetrical pectus excavatum with a Haller index of 4.2 (**Figure 2**). Echocardiography was normal and spirometry showed a restrictive ventilatory defect.

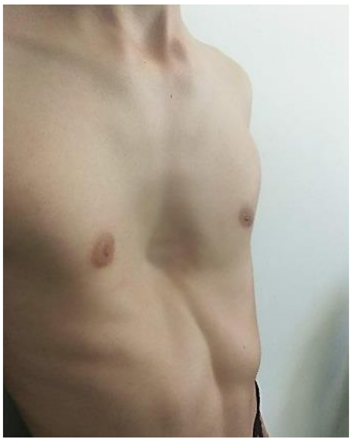

Figure 1: Low asymmetrical pectus excavatum with costal flaring.

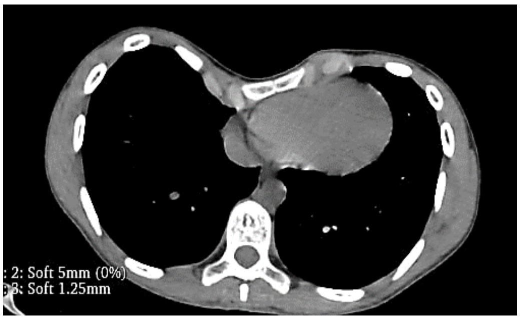

Figure 2: CT scan showing low asymmetrical deformity.

After a psychiatric evaluation and the patient's consent, we opted for the Nuss procedure to surgically correct the anatomic anomaly. For this, we created a 3D segmentation of the chest wall using DICOM-native thin (1.25mm) CT images and 2 softwares: the 3D slicer (Harvard University, National Institute of Health) and Mehmixer (Autodesk, San Rafael, CA). The software provided a stereolithographic file showing a chest excavation covering three intercostal spaces, allowing us to simulate the surgical correction using two parallel bars on transversal sections of the digital prototype. Each bar was placed on the superior then the inferior extremity of the excavation's endothoracic side. This was achieved using an extrapolation on the digital anatomic model of the defect (**Figures 3,4,5**).

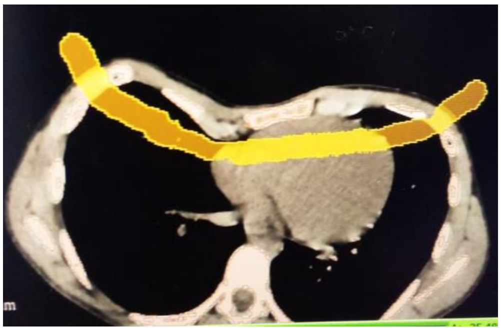

Figure 3: Bar going through the upper limit of the deformity.

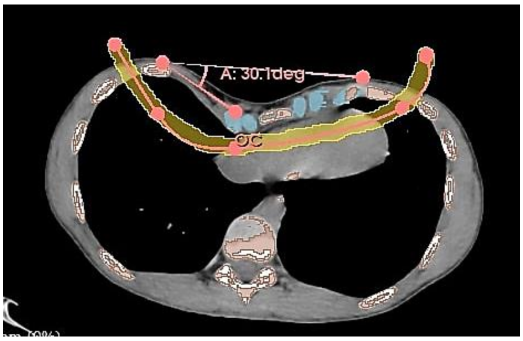

Figure 4: Bar going through the lower limit of the deformity.

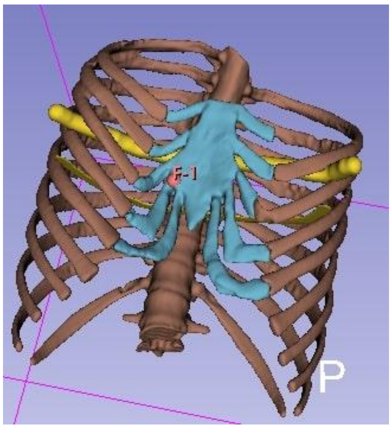

Figure 5: Anatomic model of the thorax with the two parallel bars in place.

We also simulated a correction using two diagonal bars crossing over the deepest point of the subcutaneous side of the excavation, recording the length, angle of crossing, and their introduction and extraction sites (**Figures 6, 7**).

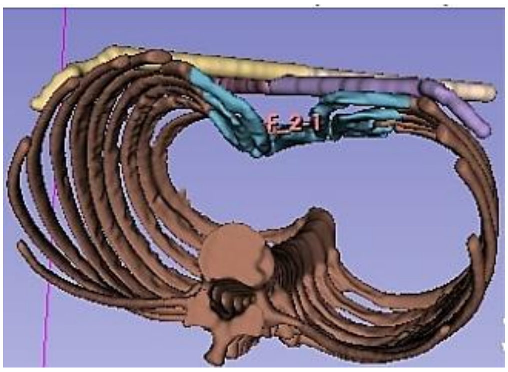

Figure 6: Digital anatomic model of the thorax with two cross bars in place. The F point represents the deepest point of the deformity.

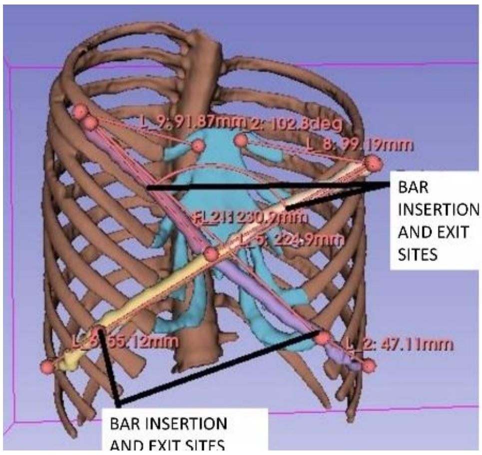

Figure 7: Digital anatomic model of the thorax with two cross bars in place, showing the length of the bars as well as the crossing angle and insertion and extraction sites.

The anatomic model of the chest wall and the parallel bars were both printed in plastic (**Figures 8 & 9**) (Ultimaker®). We opted for the crossed-bar technique. The plastic prototypes were used preoperatively to determine the correct length and served as base models for the metallic implants (**Figure 10**).

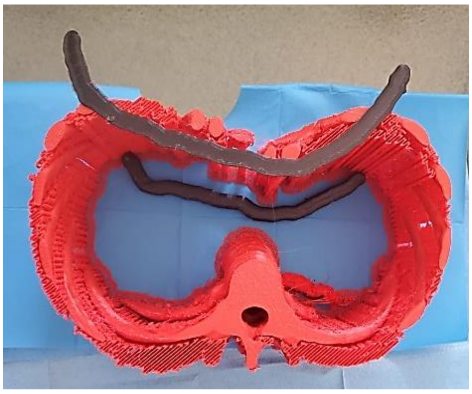

Figure 8: Anatomic model with two parallel bars

Figure 9: Anatomic model of the deformity with two cross bars.

Figure 10: Preoperative preparation of the metallic bars.

The patient underwent a Nuss surgery using two crossed bars, preceded by an elevation of the sternum using 2 steel wires hooked on a crane system and CO2 exsufflation at the time of the bar's insertion. In our experience, we only use one stabilizer per bar, introduced superiorly under the pectoralis major, as close as possible to the sternum, with a slight bending of the bar at the junction site to prevent any deviation of the stabilizer. We completed the procedure with an exsufflation of the pleural space until no air leakage remained. A postoperative chest tube was not necessary. Total operation time was 60 minutes, with no significant postoperative complications and excellent clinical and esthetical outcomes (**Figures 11 to 15**). The patient was discharged three days after the surgery.

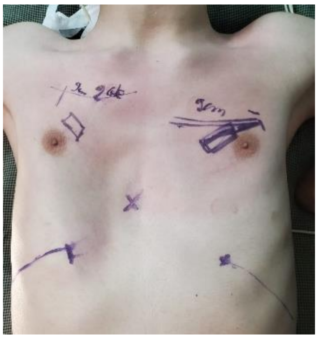

Figure 11: Perioperative schematization of the insertion and extraction sites landmarks as well as the placement of the stabilizers following simulation data.

Figure 12: Patient positioning and preparation of the crane system.

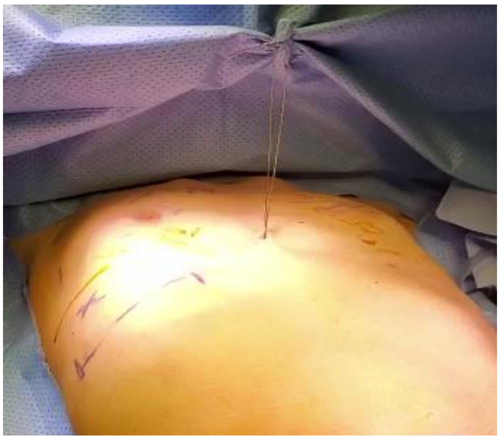

Figure 13: Sternal elevation using two steel wires hooked on a crane system.

Figure 14: Thoracoscopic view of the mediastinum after sternal elevation showing the large opening of the sterno-mediastinal space and visibility of the left anterior costal margin.

Figure 15: Post-operative esthetical outcomes.

DISCUSSION

The use of 3D printing in both medicine and surgery [10-11] is becoming more popular in the last decade. It has been proved to be very beneficial in thoracic surgery, especially in neoplastic disease [12]. However, few cases were published on its utility in the management of thoracic deformities [8-9].

Compared to previously published reports on 3D technology, our case tackles a severe form of pectus excavatum that requires the use of multiple bars. The question remained on whether the parallel or the crossed bar technique would be better. 3D printing helped solve this dilemma: an excavation going over 3 intercostal spaces would require 3 parallel bars but can also be corrected with two crossed bars. The later would lift several spaces and conform to the patient’s particularly rigid chest wall (as proven by the restrictive ventilatory defect and activity limitation). Moreover, the crossed-bar technique can correct the costal flaring, reducing consequently the cost of surgery in a low-revenue country.

This case illustrates the undeniable contribution of 3D technology in the minimally invasive surgery of pectus excavatum. Providing tools to create a step-by-step simulation of the surgical act, with precise measuring of the bar’s dimensions, their disposition (parallel or diagonal), insertion and exit sites, and, most importantly, preparing the implants in advance. This contributes crucially to the reduction of operating time: 60 minutes in our case as opposed to 90 minutes in a similar case operated by our team. 3D digitalization of the chest wall anomaly can also be useful in obese patients, women, or when the deformity is hidden by adipose tissue where the classic operative preparation of the implants may be inexact. Prolonged Nuss operation time due to multiple insertion attempts after operative preparation of the bars was reported by several authors [9]. Multiplied attempts due to inexact measurements increase complications risk; as the repeated introduction of the bar can cause lesions of the neurovascular intercostal bundle, haemothorax, or a cardiac wound ergo, becoming a stressful procedure for the untrained surgeons.

In Lin et al. series [9], a compilation of 10 cases of corrected pectus excavatum using the Nuss procedure and 3D printing. The median preoperative Haller index was 3.48 and the median postoperative Haller index was 2.75 for a surgical time average of 59 minutes versus 69.5 minutes in a second series by the same authors in which they opted for the classical surgical technique.

Furthermore, sternal elevation is for us, as for most authors [13], an indispensable tool, greatly facilitating the surgical operation by creating a large opening in the sternomediastinal space. It is even more useful in a severe cases of pectus excavatum, as in our patient. Sternal elevation in our case allowed visibility, including the left anterior costal margin.

In 2009, Lai [14] developed a digital procedure that used CT imaging to appreciate the length of the bars and predict its curves following the chest wall angles. 3D printing can simplify this process by creating a physical and malleable prototype of the implants that can be used as a mould to create the metallic bars. Additionally, 3D printing of the anatomic model and the bars prototypes is a teaching material for young surgeons in training; it also helps to simplify the procedure for patients and prepare them for surgery, especially those with a history of clinical depression or anxiety disorders, thus reducing preoperative stress and improving acceptance of the implants.

For our patient, the cost of the 3D printing was covered by a university-backed research project. In Lin et al. published series [9], the cost of the procedure was of 10 US dollars, testifying of the rapidly decreasing cost of 3D printing following the vulgarisation of its use in the medical field during the last decade.

CONCLUSION

The use of 3D printing in the minimally invasive surgery of pectus excavatum provides a simulation of the surgical technique and, therefore, vulgarises the NUSS procedure. A procedure known to rely heavily on the experience of the surgical team. However, it should in no way change the basic principles of the Nuss procedure especially the careful dissection of the mediastinal space under thoracoscopic observation and sternal elevation, these steps being more and more recommended in the current literature. It is also interesting to highlight that 3D printing, rather than being an additional task for the surgeon, is more of a collaborative work between the surgical team, biomedical engineers, and radiologists.

Conflict of Interest and Funding: None.

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