Three-dimensional surgical simulation-guided navigation in thoracic surgery: a new approach to improve results in chest wall resection and reconstruction for malignant diseases

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Abstract

OBJECTIVES: Oncological surgery of the chest wall should be performed to achieve free margins of at least 2 cm for metastasis or 4 cm for primary tumours. When the lesion is not visible or palpable, difficulty in identification may lead to a larger incision and a resection wider than is necessary.

METHODS: We report three cases of non-palpable metastatic chest wall lesions in which the preoperative surgical planning and the intraoperative identification of the tumour, and thus the subsequent chest wall reconstruction, was supported using computer-based surgery.

RESULTS: The application of high-resolution three-dimensional imaging technology and navigational systems is used in preoperative surgical planning to provide virtual simulations of a patient’s skeletal changes and new soft tissue profile. Intraoperatively, a mobile navigation probe was used to identify the lesion, matching surgical landmarks and the preoperative computed tomography imaging, achieving the radical resection of the tumour with correct but not excessive surgical margins. Two patients underwent partial sternectomy followed by sternal allograft reconstruction. The third patient underwent chest wall resection followed by reconstruction using titanium bars and vicryl mesh. In all cases, the postoperative period was uneventful. After a follow-up period of 13.9 and 8 months, respectively, all patients are disease free, without complications.

CONCLUSIONS: Application of navigation technology in thoracic surgery should be encouraged because it is easy to use and requires a limited learning curve.

Keywords: Thoracic surgery • Chest wall • Sternal transplantation • Simulation-guided navigation • Computed-aided surgery • Virtual surgery simulation

INTRODUCTION

Surgery of the chest wall is a challenging situation, mainly for two reasons: resection of a large portion of the chest wall requires a careful reconstruction to avoid secondary complications [1]. Sometimes, it is necessary in order to treat patients with focal non-palpable chest wall lesions. In these cases, surgery should be performed to achieve free margins of at least 2 cm for metastases or 4 cm for primary tumours [2]. Obviously, when the lesion is not visible, difficulty in identification may lead to a larger incision and a resection wider than is necessary. Computer-based surgery (CBS) is an emerging technology that combines a number of skills to improve health care. High-resolution three-dimensional (3D) imaging technology and navigational systems are increasingly being used in surgery to experiment different surgical procedures, for preoperative surgical planning and to provide virtual simulations of a patient’s skeletal changes and new soft tissue profile [3, 4, 5]. A further application of these technologies in thoracic surgery could be the correct intraoperative identification of non-palpable chest wall lesions, to obtain safe, but not unnecessary, free resection margins and to plan the best reconstruction technique. We report three cases of metastatic non-palpable chest wall lesions. Two patients were treated with partial sternectomy and followed by sternal allograft (SA) replacement [1, 6]. The third patient underwent chest wall resection followed by reconstruction using titanium bars and vicryl mesh. To the best of our knowledge, this is the first application of this technology in thoracic surgery.

CASE SUMMARIES

The patients’ data are reported in Table 1.
The patients with sternal metastases from breast carcinoma underwent partial upper sternectomy followed by sternal reconstruction using an SA. The implantation technique of the SA has been reported previously [1, 6]. The third patient who had metastases from colorectal adenocarcinoma underwent chest wall resection followed by reconstruction of the chest wall using titanium bars and vicryl mesh. The postoperative period was uneventful in all patients. At the last follow-up, all patients were in good clinical condition without disease recurrence. Until now, no complications related to the surgical technique have been reported in our patients.

### TECHNIQUE OF 3D NAVIGATION

In the case of sternal lesions, we reconstruct the anterior chest wall with an SA. The first step is the selection between the SAs stored in our tissue-bank. The decision about the graft selection and thus positioning is made thanks to a virtual simulation using the iNtellect-Cranial-Suite1.0, which is the software tool of the eNlite Navigation System (Stryker, Freiburg, Germany). The software makes it possible to import different computed tomography (CT) datasets and to merge them together using an iterative-closest-point procedure. The algorithm is natively made to merge datasets of the same patient (CT, PET etc.), but it can also be used to merge different datasets (for example, the patient’s chest and the SA). This makes it possible to find the ‘best fit’ of the graft in a specific patient [3, 4] (Fig. 1). The position can be further refined manually, if the surgeon finds the result of the automatic procedure inadequate. The software also allows the neoplastic tissue to be segmented. This makes the tumour ‘visible’ and can be used during navigation in the operating theatre (Fig. 2). Furthermore, it is possible to virtually plan the resection with

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SA: sternal allograft; LN: lymph node; LIMC: left internal mammary chain.

Figure 1: Preoperative surgical planning. CT scans of the patient’s chest and of the sternal allograft were loaded in the navigation system. The software is able to simulate the repositioning of the allograft after sternal resection. The tumour is clearly identified (arrow), and thus the resection-reconstruction can be planned respecting correct surgical margins.

Table 1: Patient characteristics
correct surgical margins, according to the 3D surgical landmarks of the chest wall. After choosing the best allograft for each patient, the operation is scheduled. In the operating theatre, after defining the necessary operating field, the tracker is screwed into the patient’s chest. In our cases, we fix the tracker on the upper portion of the patient and allograft manubrium (Fig. 3A and B). The CNS is then started. The CNS consists of making the real patient visible and his/her orientation in space decipherable by the navigation software, following the same coordinate system as the recorded preoperative CT scan. This technique orients the patient according to the CT scans by indicated well-identifiable points on the chest, and relates them to the virtual patient image shown on the navigator screen (Stryker eNlite Navigation System). The registration process consists of identifying the same points used during preregistration on the real patient’s chest wall or sternum, so-called ‘point-to-point registration’. The procedure is completed with a surface registration collecting casual points on the patient’s chest wall and defining a virtual model of the chest wall. The same preregistration and registration procedures are also performed on the SA, fixing the tracker in the upper part of the manubrium as well (Fig. 3B). The landmarks used to obtain surgical orientation are planned using the preoperative CT scan (Fig. 3C and D). We generally choose some anatomical landmarks that are the simplest to find intraoperatively, such as the clavicle heads, the angle of Louis and the ribs. The overlap with the images obtained virtually allows us to shape the SA to fit perfectly with the patient’s chest wall defect (Fig. 4). CNS also allows a double-check to correctly identify the position of the non-palpable tumour using a mobile tracking system. Indeed, using the prerecorded CT scan images that match the intraoperative position of the patient, we can pinpoint the tumour position, on the chest wall surface, using the tip of the mobile tracking system (Fig. 5). The tumour volume can be obtained by either manual segmentation or automatic segmentation. It is thus possible to set a warning signal, emitted when the pointer is near the tumour according to a predetermined distance (Fig. 6). In this way, the resection can be performed with safe, but not excessive, resection margins. In Patient 2, this procedure was also used to identify the PET-positive lymph node of the left mammary artery chain from the anterior surface of the chest wall. This made it possible to remove the lymph node en bloc with the surrounding chest wall and the hemisternum (Fig. 5). The pathological study confirmed the lymph node as metastatic. In Patient 3, the same procedure was used to correctly identify the tumour and thus to achieve a radical chest wall resection with correct surgical margins. In this case, we used the preoperative CT scan for prerecording and recording procedures with identification of surgical landmarks that allowed a point-by-point identification of the lesion during the operation with the mobile tracking system.

DISCUSSION

Primary or secondary tumours of the chest wall often require challenging operations. The treatment of these tumours needs wide resection with good surgical margins, which is sometimes very difficult to achieve in the case of non-visible or palpable lesions. Moreover, the evaluation of the surgical margins cannot be confirmed until decalcification is completed, usually after 7–10 days postoperatively. As a result, wider, and sometimes unnecessary, osseous margins are often made in order to avoid local disease recurrence [7]. Large chest wall defects consequently need careful and anatomically correct reconstruction techniques to avoid secondary complications, such as respiratory failure, infections,
thoracic organ damage, chronic pain, functional limitations of the upper limbs and cosmetic damage.

Over the years, different methods have been used to aid the surgeon in the localization of chest wall lesions; these include pre-operative identification and marking of the skin overlying the tumour, tomography/scintigraphy scans with radio-opaque markers, wire guided-biopsies with or without methylene blue staining, etc. [8–10]. Unfortunately, none of these techniques allows an accurate localization of the tumour, and in any case without a clear identification of the lesion the surgeon still needs a larger incision and a wider resection. An interesting approach was reported in 1998, using a hand-held gamma probe, originally...
designed for the localization of sentinel lymph nodes in the case of breast cancer and melanoma, to perform radionuclide-guided rib lesions biopsies [10]. Other groups subsequently used this approach with a sensitivity and specificity of 100% for diagnostic intent [8, 9]. The use of an intraoperative navigation probe allows an accurate localization of the lesion, and optimal incision placement, and the correspondence of the target lesion is unaffected by changes in patient positioning [8, 10].

Figure 5: Intraoperative localization of the non-palpable metastases. The software will indicate the collision between the pointer-tip and the localization of the metastases on CT scan images, matched to the patient, with a visual (the monitor frame becomes red) and audible signal. It is possible to set the desired resection margin within the navigator to indicate to the operator that the collision has occurred.

Figure 6: Patient 3: the software shows the resection margins and the tumour volume (green area).
A further advance in this field has been the introduction of CBS [3–5]. This technology has been used for several years in orthopedic surgery, cranio-maxillofacial surgery, orthognathic surgery and neurosurgery, but to the best of our knowledge this is the first report of the application of CBS in thoracic surgery. In our experience, this technique has two important advantages over all the other reported techniques for localization of bone lesions. First of all, it is possible to upload the preoperative CT scan and/or PET scan in order to obtain correct surgical planning with a virtual simulation of the osteotomy and of the subsequent reconstruction. Different surgical strategies can be simulated on the computer, choosing the best one for that patient. During the operation, it is then possible to synchronize the intraoperative position of the instruments with the imaging of the patient’s anatomy obtained by CT scan, recreating step by step, point by point the surgical procedure simulated the day before on the computer. In particular, this technique is very useful in the case of allograft reconstruction of a tissue defect [4]. CBS leads to better allograft shaping based on computer simulation and thus a better allograft fit. Earlier allograft integration and less postoperative pain can probably be expected if the gap between the host bone and the allograft is smaller and the reconstruction is more stable. The second, and probably the most important, advantage of this technique is the possibility to accurately identify the localization and the volume of the tumour, with a target registration error (TRE) ranging from 0.6 to 1.6 mm [3]. Indeed, the use of the hand-held navigation probe and the tracker allowed us to have direct visualization, on the video-display of the navigation system, of the localization, diameter and margins of the bone lesion. The resection can be performed safely with correct surgical margins and without excessive tissue removal. In our cases, the pathological evaluation of the surgical margins on the surgical specimens matched the expected margins on computer simulation. The major limitation of this technology is the cost of the hardware and software. This procedure is also time-consuming. The preoperative process requires more or less 4 h to load the images and to plan and simulate the operation. In our experience, the intraoperative phase requires around 2 h and involves a further two surgeons, in the case of allograft replacement. Of course, this is a preliminary experience and further studies based on a larger number of patients are mandatory to standardize the procedure and to verify the reproducibility of the technique. Application of navigation technology in thoracic surgery should be encouraged because there are various commercially available easy-to-use systems that require a limited learning curve.

Conflict of interest: none declared.

REFERENCES


