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# Reconstruction of Thoracic Postresection Defects by TiNi-based Implant

**E.B. Topolnitskiy[1,*], G.Ts. Dambaev[1], V.N. Hodorenko[2,3], S.V. Shchadenko[1,4], V.E. Gunther[2,3]**

[1] Siberian State Medical University, Tomsk, Russia
[2] Tomsk State University, Tomsk, Russia
[3] Research Institute of Medical Shape-Memory Materials and Implants, Tomsk, Russia
[4] Tomsk Polytechnic University

*Corresponding author: E.B. Topolnitskiy, email: e_topolnitskiy@mail.ru

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## Abstract

This article describes original surgical methods and the results of reconstruction of postresectional pericardium defects, diaphragm defects and chest wall defects with the use of nickel-titanium implants. The aspects of integration of developed surgical methods and methodology in the creation of implants by means of modern computer technologies during surgical planning in thoracic oncology are presented. The aspects of integration were first studied during surgical experiments on animals and then the following application in clinics. The reconstruction of pericardium defects in 17 cases, the diaphragm defects reconstruction in six cases and chest wall defects reconstruction in six cases will be presented. Satisfactory and excellent functional results were achieved following the surgeries. Respiratory function disorders and instability of the rib cage were not revealed in the late postoperative period under the dynamic control.

## 1 Introduction

The improvement of resuscitation and surgical technologies led to a wide adoption of expanded combined resection and reconstructive surgical operations in thoracic oncology. The expected result of intervention of that type is the resection of organs affected by malignant tumors as well as the resection of adjacent anatomic structures involved in pathologic process. For the full-fledged patient rehabilitation the correction of postresectional pericardium defects, diaphragm defects and chest wall defects is required [1-3].

Today the utilization of synthetic materials and implants for reconstructive surgery is widely used. This approach allows the simplification and standardization of the reconstructive stage as well as the reduction the duration and injury rate of surgical intervention. In such cases, the number of issues related to the transplantation, specifically the shortage of plastic material or the risk of transmissive infections, are absent. Moreover, the legal and ethical questions associated with allotransplantation are avoided. However, in the case of the use of synthetic materials, the personalized creation of implants along with the application methodology of such personalized implants are necessary [4-6].

In the preoperative period of surgical planning of such intervention, it is necessary to clarify the size and location of the oncologic process with consideration of individual anatomical peculiarities of the patient. In order to solve the stated issues, 3D computer graphics and computer 3D modeling started to be used more extensively, particularly for computer reconstruction of anatomic structures and patient organs in 3D format.

The utilization of computer 3D modeling based on segmentation of patient medical images in preoperative period allows for more precise surgery planning, including prognostication of intervention volume and probability of postoperative complications. This leads to the reduction of surgical duration, surgical injury rate, patient rehabilitation time and costs of patient recovery.Moreover, use of 3D models of anatomical structures and organs of patients promotes better communication between doctors, which is indispensable for interdisciplinary. In addition, the computer 3D modeling along with modern 3D printing and molding technologies permits the obtainment of implants for a particular patient within a limited time and under financial constraints [7].

The introduction of bioadaptive materials based on nickel-titanium into different areas of medicine has opened new possibilities for surgical treatment of oncology patients requiring the reconstruction of different anatomical structures with extensive defects within chest. In order to boost efficiency of surgical intervention, we developed original methods of reconstruction of postresectional pericardium defects, diaphragm defects and chest wall defects with the use of nickel-titanium implants. The developed method was evaluated in experimental and clinical applications.

## 2 Experimental

The series of experiments was conducted on 30 mongrel dogs with a body mass ranging from 10 to 16 kg. The research was conducted in accordance with the "European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes" (Strasbourg, 1986). The nickel-titanium implants used for research were fabricated at Institute of Medical Materials and Shape Memory Implants in Tomsk.

The surgery preparation, anesthetic procedure and running of postsurgery period for all animals were identical. The modeled defects were plastically reconstructed with the nickel-titanium implants. The animals were equally divided into three groups according to the localization of the defect. In group 1, animals (n=10) underwent combined pneumonectomy with resection and plasty of the pericardium. In group 2 (n=10), the diaphragm resection and plasty were performed. In group 3 (n=10), resection and chest wall plasty were done.

The implant is the thin profile fabric with a mesh sizes of 120-240 μm, woven by the textile technology of super-elastic filaments made of nickel-titanium alloy with a thickness of 60 μm. The filament is composed of composite material comprising a core made of nanostructured monolithic nickel-titanium and a porous surface layer of titanium oxide 5-7 μm thick. The presence of monolithic nickel-titanium alloy inside the oxide shell improves strength properties of the composite material, and the porous scaly surface provides high adaptability of the material in body tissues. The implant has capillary properties due to the fine-meshed structure and porous sheath of a composite filament, which creates the possibility of deliberate saturation of the implant with the antibacterial solutions and its application in contaminated wounds.

The clinical observation of the animals was conducted by means of radiographic monitoring during postoperative period. The animals were withdrawn from the experiment on the 7th, 14th, 30th days and on the 3rd and 6th months, followed by macroscopic and microscopic description of the area of intervention. The implant with the surrounding tissue regenerate was examined with a scanning electron microscope QUANTA 200 3D (the FEI Company, USA). Tissue regenerate and adjacent tissues were subjected to histological examination.

The study included 17 patients with locally advanced non-small cell lung cancer (NSCLC) who underwent surgical intervention for lung resection and plasty of the pericardium by the developed technology. The 17 pneumonectomies were made with resection from one to four neighboring organs and structures due to the tumor ingrowth.

The study included five cases of use of the nickel-titanium mesh implant for the reconstruction of the diaphragm in clinical practice. In one case, the implant was used for total replacement of the left diaphragm cupula after it has been removed due to a malignant tumor. In other cases the implants were used to strengthen the diaphragmatic suture for the extended combined intervention regarding locally advanced malignancies of the lung with invasion into the diaphragm.

The study included six patients with malignant tumors of the chest wall who underwent chest wall resection and subsequent reconstruction with the use of reinforcing nickel-titanium implants. Five patients had only ribs affected, one had combined lesions of the ribs and sternum. Malignant tumors were observed in three cases with NSCLCand invasion into the chest wall. In one case there was plasmacytoma, in one case was breast cancer, and in final case was the solitary metastasis of renal cancinoma. The subtotal resection of the sternum and three ribs was conducted in one case, resection of two ribs was made in two cases, resection of three ribs done in one case and resection of four ribs performed in two cases. The area of the formed defect of the chest wall ranged from 80 to 420 cm2. In four patients the resection of the chest wall was combined with pulmonary resection. The wedge resection in one case, lobectomy in two cases and pneumonectomy in one case.

In the preoperative period, to improve diagnostics and surgical planning, we used anatomical computer 3D modeling based on CT scans processing.

# 3 Results and discussion

*Experimental results conducted on dogs*.

During repair of postresection defects of different chest structures the filament pores and implant cells were rapidly filled with tissue fluid due to the capillary properties of the implant material. Tissue fluid, due to the surface tension forming a film, thus creates a barrier separating the pericardial and pleural cavities, to a certain extent separating the peritoneal cavity from the pleural one and preventing air leakage from the pleural cavity at the site of resection.

In none of the cases implant migration and postoperative complications were noted. Morphological examination on day 7 after surgery revealed accumulation of granulocytes and agranulocytes, minor edema, and hemorrhagic foci with signs of organization at the site of implant contact with the pericardium, diaphragm, or chest muscles. At the outer and inner sides of the implant granulation tissue was formed.

On day 14, the formation of tissue regenerate was presented by loose connective tissue with moderate content of fibroblasts and fibroblast-like cells and collagen fibers with a tendency to be perpendicular in structure. In groups 2 and 3, organization foci with moderate infiltration replaced hemorrhagic foci in the diaphragm and chest wall muscle fibers. Muscle bundles located at a distance from the area of interest had usual structure. In group 2, plethoric vessels and numerous fibroblasts and fibrous fibers were found in the adipose tissue. Small foci of adipose tissue degeneration and edema surrounding the fibrous tissue were also noted. In some fields of view, signs of fibrosis were seen in the adipose tissue of the greater omentum fixed to the implant. In group 3, fibrous tissue of different degrees of maturity was found at the ends of resected ribs, solitary newly formed young osseous trabeculae were seen in the bone tissue.

On day 30, the structure of tissue regenerate around the defect along the implant surface differed from that at the previous term only by the degree of granulation tissue maturity; collagen fibers were arranged along nickel-titanium filaments and formed bundles. At later terms, organ-specific tissue differentiation in the newly formed regenerate occurred. At later terms (6 months), the morphological picture of the regenerate on the implant surface showed little changed. In group one animals, the inner layer of the regenerate was completely lined with single-layer epithelium. In group three, osseofibrous callus with cartilaginous tissue fragments was formed at the ends of distal and proximal rib residues.

Scanning electron microscopy showed that connective tissue formation started from the filament surface at the site of its knots, while filling of the implant with tissue regenerate progressed from the peripheral to the central zones of mesh cells(Fig.1). The newly formed tissue around the defect and on the implant surface had fibrillary structure. Collagen fibers densely wrapped the nickel-titanium filaments and formed peculiar plexuses resembling “wicker fence”, thus strengthening and sealing the contacts. By the 6th month after surgery, the strength of implant contact with chest wall tissue in group 3 considerably increased.

Morphological examination of the operated area in all animals attested to the formation of structurally similar tissue regenerate replacing the defect; no appreciable changes in adjacent organs disturbing the function of the organ were noted.

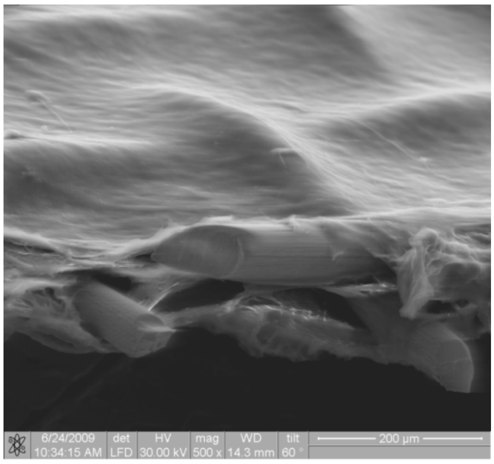


Fig. 1. Microstructure of tissue regenerateon 30 dayafter pericardium plasty, ×500. Scanning electron microscopic views of thecollagen fibers and bundles closely wrappednickel-titanium filament. Inner surface of the tissueregenerate acquired the implant relief

*Clinical results of postresectional defects replacement on anatomic structures of the chest*. Postoperative period was satisfactory. Intraoperative and postoperative complications associated with the surgery were not revealed. In the postoperative period patients underwent ultrasound monitoring with the control of pericardial fluid volume. The excess of fluid volume was not identified in any case. In all cases, the nickel-titanium implant and autologic tissues were used for the substitution of the post-resection defects of the chest wall. The displaced flaps of pectoralis major and the latissimusdorsi were used for the reconstruction of soft tissues. The rib implants and mesh made of nickel-titanium were used to restore osseous structures.In all cases, we were guided by the generally accepted approach that the reconstruction of the defects of the rib cage is necessary to prevent cardiorespiratory disorders under the following conditions: 1) three and more ribs are involved into the resection; 2) after subtotal or total sternum resection; 3) when the defect area is over 100 cm2 [6, 8].

Depending on the size and localization of post-resection defect different variants of combined plasty were used to stabilize the chest wall and prevent paradoxical respiration. The options of combined plasty of post-resection defect of the chest wall are presented in Table 1.

Table 1 Options of combined plasty of chest wall defects

| Reconstruction options | Absolute number of patients | % |
|---|---|---|
| Nickel-titanium mesh + transferedpectoralis flap | 1 | 16,7 |
| Nickel-titanium mesh + transfered lateral thoracodorsal flap | 2 | 33,3 |
| «Sandwich» of mesh and rib implants made of nickel-titanium + local tissues | 1 | 16,7 |
| «Sandwich» of mesh and rib implants made of nickel-titanium + transfered pectoral flap | 2 | 33,3 |
| Total | 6 | 100 |

The category of surgical interventions under discussion is inevitably associated

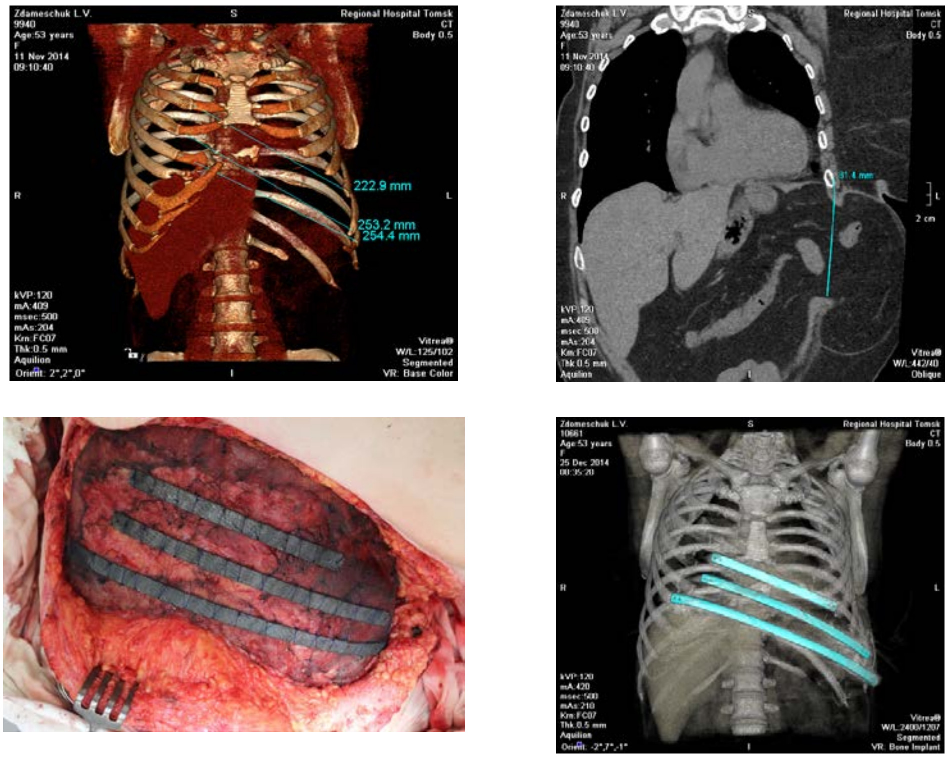


Fig. 2. Patient. A: a, b – giant postresection chest wall defect combined with ventral hernia; c – preoperative CT scan.; d –chest wall reconstruction; d – «Sandwich» of mesh and rib implants made of nickel-titanium with local tissues; d – postoperative CT scan (42 day)

with painin the surgical wound, violation of the biomechanics of breathing due to drainage, air or pleural fluid, and sometimes a decrease in respiratory surface of the lungs depending on the volume of removed lung tissue.

During surgery and in the postoperative period there were no lethal outcomes. In the early postoperative period complications occurred in two patients (33.3%) after reconstruction of the chest wall in the form of seroma and exudative pleurisy. All complications were managed to be resolved. Satisfactory and excellent functional results by Enneking rating system were achieved. Respiratory function disorders and instability of the rib cage were not revealed in the late postoperative period under the dynamic control.

# 4 Summary

Thus, the tissue implant of super-elastic nickel-titanium filament is good plastic material and it allows the correction of extensive post-resection defects of the pericardium, diaphragm and chest wall. The newly formed tissue grew through the mesh implant with the formation of a single tissue regenerate, which does not complicate heart function, the excursion of the diaphragm and the chest wall. At the present stage it is necessary to widely use the possibilities of computer modeling for planning reconstructive procedures in thoracic oncology to improve the quality of surgical intervention.

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