Infectious spondylitis encompasses a large group of diseases of the spine characterized by the destruction of the vertebrae and intervertebral disks, as well as the involvement of paravertebral soft tissues and the spinal canal. Given the etiology of spondylitis, two variants are most frequently diagnosed [1]:

1) non-specific spondylitis and osteomyelitis of the spine (primary, secondary hematogenous or septic, and secondary post-traumatic. Given the destructive lesions limited by one segment, the term “spondylodiscitis” is also often used [2]);

2) tuberculous spondylitis (spinal osteomyelitis) or Pott's disease, which develops as a result of the dissemination of the Mycobacterium tuberculosis complex from infected lungs or lymph nodes. A rare simple form of tuberculous spondylitis is so-called “TB-spondylitis of BCG etiology,” which involves damage in infants with multisegmental processes [5, 6];

The main objectives of surgical treatment for infectious spondylitis include the radical removal of the destroyed tissue, recovery of the supporting ability, stability, sagittal balance, and the preservation of the capacity for further spinal growth [7, 8]. The traditional material used for the replacement of post-resection defects of the anterior column is bone autografts (i.e., fragments of the rib and iliac crest); however, their use is associated with a high risk of developing pseudoarthrosis (≥40 %), the long-term loss of surgical correction, and the development of pain syndrome in the area of auto-bone sampling (donor site disease) [9].

The introduction of modern posterior spinal instrumentation enables effective reconstruction of the affected region of spine. However, the possibility of the use of anterior stabilization implants in pediatric spine surgery have not been studied to date [10].

The gathered experience of the Clinic of Pediatric Surgery and Orthopaedics of the Saint Petersburg Research Institute of Phthisiopulmonology has provided the long-term results of children who have received surgical treatment for infectious spondylitis by reparative surgery of the spine with the use of titanium mesh block cages for front spine stabilization (Harms meshes).

The aim was to study the potential use of titanium mesh block cages to form anterior interbody fusion for the surgical treatment for infectious spondylitis in children.
Study design. This was a monocentre retrospective cohort (level of evidence – III). The patient recruitment period was from 2011 to 2014.

The inclusion criteria:
• age at the time of the surgery less than 18 years;
• the surgery was performed at a single location: Clinic of Pediatric Surgery and the Orthopedics of Saint Petersburg Research Institute of phthisiopulmonology;
• use of titanium mesh for anterior fusion;
• etiologically verified diagnosis of infection (tuberculous or nonspecific) spondylitis
• follow-up period of at least 24 months;
• availability of a full imaging (i.e., X-ray, CT) archive.

PATIENTS AND METHODS

During the study period, 319 surgeries on the spine in children were performed at the clinic. The data of 83 patients corresponding to the inclusion criteria was included in the overall analysis. The average age at the time of the surgery was 15.3 ± 2.8 years (minimum: 7 months; maximum: 17 years). Indications for surgery included: the presence of infectious destruction of the vertebrae; the presence of kyphotic deformation of the spine; neurological disorders; and the ineffectiveness of conservative antibacterial (for non-specific processes) and antituberculous (for specific spondylitis) chemotherapy for at least two months. The average duration of a therapeutic timeout (the time from establishing the diagnosis to surgery) was 16 months (minimum: 4 months; maximum: 13 years).

According to the diagnosis based on a compilation of morphological, bacteriological, and molecular genetic (PCR) studies of surgical material, the patients were divided into two groups:
Group 1 (n = 42): tuberculous spondylitis, including 33 patients with an active disease and nine patients with consequences of tuberculosis. After surgery, all patients underwent a course of comprehensive antituberculous chemotherapy in accordance with the regulated regimes, for at least 12 months.
Group 2 (n = 41): chronic non-specific spondylitis and consequences of tuberculosis, including 16 patients with monosegmental spondylodiscitis. Following surgery, at least two courses of antibacterial therapy were administered to the patients in accordance with the isolated microflora.

The general scheme of the study, including the distribution of patients according to etiology and age is presented in Figure 1.

The distribution of patients according to the localization of lesions: cervical (n = 7); thoracic (n = 27); thoracolumbar (n = 12); lumbar (n = 36); and lumbosacral (n = 3) regions, respectively. The surgeries were performed under endotracheal anesthesia. Surgical access to the reconstructed region was chosen by accounting for the localization and extent of the destruction. The anterior cervical access was used for the cervical region; the lateral transthoracic extrapleural access with the resection of the corresponding rib was used for the thoracic region; the thoraco-diaphragmatic access was used for the thoracolumbar region; and the extraperitoneal access was used for the lumbar and lumbosacral spine. In cases involving the reconstruction of more than one spinal motion segment (SMS) (three or more vertebrae) or the initial presence of a spine deformation, the surgery was performed simultaneously with posterior instrumental fixation (n = 45). This involved transpedicular, hooked, or hybrid third-generation designs (CDI) adapted for each age group (rod diameter: 3.5–5.5 mm). The average number of support elements for posterior fixation was 6. All patients underwent the radical removal of the destroyed tissues, as well as the drainage of pre-, paravertebral, and epidural abscesses. Reconstruction of the anterior column was performed using a titanium mesh block cage pre-filled with an auto-bone fragment (n = 83). A mesh was implanted into the interbody diastasis in maximum possible reclination. After surgery, a drainage tube was fixed with a layered closure of the wound. The vertical positioning of patients was performed on the Day 4 in orthosis.

Continuous recruitment in 2011-2014 319 spinal surgeries in children

The use of meshes for anterior fusion

108 patients

use of enrollment criteria for the study

Exclusion of 25 patients

use of enrollment criteria for the study

Age-related ranking

≤ 3 years 17 patients

4 < ... ≤ 6 years 16 patients

12 < ... ≤ 17 years 32 patients

7 < ... ≤ 11 years 18 patients

Etiological differentiation

Tuberculous spondylitis (n = 42)

Non-specific spondylitis (n = 41)

Fig. 1 General study design with age-related ranking and etiological differentiation of the diagnosis
The results were analyzed for all children immediately after the surgery, 6, 12, and 18 months postoperatively, and then annually. The evaluation of the long-term results of the study was performed in accordance with the regression schedule (Fig. 2).

Analyzed parameters:
1) exacerbation of the infection;
2) frequency of complications associated with the implanted interbody titanium mesh (e.g., dislocation, protrusion, etc.);
3) surgical correction of the spinal deformity (in Cobb degrees);
4) dynamics in the Cobb angle (in degrees) after the surgery;
5) dynamics of bone block formation at the site of anterior fusion (5-point quantitative scale) [11];
6) dynamics of neurological disorders (Frankel scale) [12];
7) intraoperative blood loss;
8) time of surgery.

Statistical analysis. Software Statistical Package for the Social Sciences (SPSS) version 22.0 (SPSS Inc., Chicago, IL, USA); t-criteria: 1) comparison of the average values of the angular kyphotic deformation before and after the surgery; 2) comparison of average values for the dynamics of bone block formation at the site of anterior fusion 6 and 12 months after the surgery; 3) comparison of values of operative blood loss and the time of surgery. The differences are recognized to be statistically significant at a bilateral p-level of <0.05. The pairwise correlation analysis with the ranking of the Pearson coefficient values (p ≤ 0.5 indicates a weak relationship; 0.5 < p ≤ 0.7 indicates medium power; and p > 0.7 indicates a strong relationship).

RESULTS

Exacerbation of the infection. In accordance with the post-operative examination deadline, no cases of infectious complications or exacerbation of the infectious process were identified six months after surgery; after 12 months, one case of exacerbation of the initial tuberculous spondylitis was registered; and after 24 months, no infectious complications were found (no statistically significant differences in the indices of exacerbation of the infectious process were found between the study groups; p = 0.199).

Complications commonly associated with the implanted interbody mesh (e.g., fractures, dislocations, and pseudarthrosis) were not identified in the study groups.

The indices of the angular kyphosis correction value (in Cobb degrees) are shown in Table 1.

<table>
<thead>
<tr>
<th>The evaluated segment</th>
<th>Terms of observations</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crania 6 months</td>
<td>0 0 78 5 0</td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>0 0 57 26</td>
<td></td>
</tr>
<tr>
<td>Cauda 6 months</td>
<td>0 10 71 2 0</td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>1 0 60 19</td>
<td></td>
</tr>
</tbody>
</table>

* statistically significant differences in the rate of bone block formation were revealed during the postoperative period (p = 0.009), and by the 12th month, the degree of bone block manifestation (4 and 5 out of 5 points) was significantly higher than six months after surgery.

Neurological disorders* were initially detected in 5 out of 83 patients. In all cases, the leveling of movement disorders was registered following the reconstruction of the spine. In four patients, the regression of neurological disorders appeared to be complete.
Indices of operative blood loss*

- Group 1 (tuberculous spondylitis): $M \pm m = 184.1 \pm 122.6$ mL;
- Group 2 (chronic non-specific spondylitis): $M \pm m = 137.3 \pm 88.4$ mL.

* the criterion for Livin dispersion equality indicates that the dispersions of two distributions do not differ significantly ($p = 0.245$). Therefore, the use of a $t$-test was adequate. No statistically significant differences in the rates of operative blood loss were found between the study groups ($p = 0.214$).

<table>
<thead>
<tr>
<th>№</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Pathology level</th>
<th>Evaluation on the Frankel scale</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>f</td>
<td>17</td>
<td>Th6-L4</td>
<td>Before the surgery* D</td>
<td>E</td>
</tr>
<tr>
<td>2</td>
<td>m</td>
<td>4 y 6 mos.</td>
<td>Th9-12</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>f</td>
<td>11</td>
<td>Th8-10</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>4</td>
<td>m</td>
<td>1 y 3 mos.</td>
<td>Th3-4</td>
<td>B</td>
<td>E</td>
</tr>
<tr>
<td>5</td>
<td>f</td>
<td>12</td>
<td>Th6-9</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

* $t$-test for the paired samples of 83 patients: the differences between the average values of the variables “Evaluation on the Frankel scale before the surgery” and “Evaluation on the Frankel scale after the surgery” were statistically significant ($p = 0.007$). Moreover, as indicated from the results, there is a significant correlation between the variables ($r = 0.843; p < 0.001$), indicating that these variables can be considered dependent.

**DISCUSSION**

When commenting the obtained results, the physical and mechanical properties of the implant should be primarily noted, particularly the strength and biological inertness of the titanium. This enables the extended (more than $2 \times$ SMS) anterior column defects to simultaneously and effectively be replaced without causing a biological reaction in the body of the child.

In the analysis of Russian and international medical literature databases, we could not find any information on the use of titanium mesh in children. In this regard, we compared our results with the studies that analyzed surgical treatment of infectious spondylitis in adults [13, 14].

According to Hadjipavlou et al. [15], Skaf et al. [16], and Chen et al [17], the use of bone autografts for the treatment of spondylodiscitis results in an increased risk of infectious complications; however, according to Arrington et al., grafting of an auto-bone is accompanied by chronic pain in more than $40\%$ of cases [9]. This forces the surgeons who do not have modern implants at their disposal to follow conservative treatment for spondylitis with the use of antibacterial chemotherapy, orthoses, and bed rest. However, this strategy is aimed only at the infectious agent and it is not possible to reconstruct the destroyed region, eventually resulting in the development of spinal deformities.

Zhang et al. [18] presented a retrospective clinical series which included data on 28 patients (average age: $42.7 \pm 5.8$ years) who underwent surgery for tuberculosis spondylitis using titanium mesh block cages for anterior fusion. The average term for the formation of a stable bone block was eight months, and the correction of the kyphotic deformation was $38.9 \pm 6.6^\circ$ with the loss of correction over a long-term follow-up period (4 years), which does not exceed $2^\circ$.

Won Heo et al. presented a study with similar number of patients ($n = 28$) [19]. Radical spinal reconstruction was performed for infectious spondylitis with the use of titanium mesh in all cases. The average age of the patients was $55.7$ years and the long-term observation period was 6 to 64 months. There were no complications associated with implanted titanium mesh and the surgical correction loss at the end of the observation period was $4.8^\circ$.

There are only single reports of the complications associated with the fracture and migration of titanium mesh block cages, which are not of statistical significance [20, 21, 22].

**CONCLUSIONS**

The treatment for infectious spondylitis in children requires a comprehensive approach which includes: 1) the early diagnosis and chemotherapy (in the case of non-specific spondylitis, antibacterial therapy of narrow spectrum of action is required; in case of tuberculosis spondylitis, antituberculous chemotherapy is required); 2) the implementation of spine reconstruction using titanium mesh block cages. This enables a reduction in the risk of both immediate and long-term postoperative complications. The formation of a reliable bone block in the region of the anterior reconstruction contributes to shortening the term for the removal of posterior retaining
structures while maintaining reliable intraoperative correction of the deformity and the potential for further growth of the child.

**Clinical case.** Patient M., aged 2 years 11 months with the consequences of previous generalized tuberculosis: tuberculous spondylitis, soft tissue tuberculosis of the right foot. Neurological status: type E by Frankel scale.

**Fig. 3** Patient M. aged 2 years 11 months: CT (a and b) before the surgery, kyphotic deformation of Th4-8 41°. X-rays (c and d) after surgery of Th4-8 (anterior interbody fusion using titanium mesh with an auto-bone, posterior instrumental fixation of Th3-9 with a multi-support system of eight hooks). Thoracic CT eight months after surgery (e). Formation of the block inside the mesh is estimated at 4 points (no area of resorption with contact associated with reactive contact sclerosis)

**REFERENCES**


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**Information about the authors:**

1. Denis G. Naumov, St. Petersburg State Pediatric Medical University of the RF Ministry of Health, St. Petersburg, Russia
2. Alexander Iu. Mushkin, M.D., Ph.D., Saint Petersburg Scientific Research Institute of Phthysiopulmonology, Clinic of Pediatric Surgery and Orthopaedics, St. Petersburg, Russia, a chief researcher, Head of the Clinic of Pediatric Surgery and Orthopaedics, Coordinator of Extrapulmonary Tuberculosis direction, Professor; **Corresponding author:** aymushkin@mail.ru.
3. Andrei A. Pershin, M.D., Ph.D., Saint Petersburg Albrecht Scientific-and-Practical Center of Medical and Social Expertise, Prosthetics and Rehabilitation of the Disabled, St. Petersburg, Russia, Head of the Department.