SELECTED LECTURES

ON SPINE SURGERY

TUBERCULOSIS OF THE SPINE IN CHILDREN: A MODERN CONCEPT

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The data presented in the lecture are based on the modern concept of diagnosis and treatment of spinal tuberculosis in children and on the last 25 years' experience of surgical treatment of more than 350 such patients aged 8 months to 17 years. Being the head of the Clinic of Pediatric Surgery and Orthopedics (formerly the Children's Bones and Joints Tuberculosis Surgery Department) of the St. Petersburg Institute of Phthisiopulmonology for the past 17 years, the author expresses gratitude to his teachers and colleagues — surgeons, anaesthesiologists, phthisiatricians, rehabilitologists, pediatricians, surgical and desk nurses, without whom the results would hardly have been achieved, which allow considering the national experience in the surgical treatment of bone tuberculosis in children one of the most successful in the world today.
Key Words: spinal tuberculosis, tuberculous spondylitis, children.

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Tuberculous spondylitis is a specific infectious spinal disorder caused by mycobacteria belonging to the so-called tuberculosis complex *(M. tuberculosis complex)*. In the vast majority of cases, spondylitis develops as a result of generalization of infection caused by *M. tuberculosis humanus* from a primary focus in the lungs or lymph nodes [3, 6, 8, 14]. In extremely rare cases, specific spondylitis may result from the pathological course of vaccinal process caused by *M. bovis* BCG vaccine strain [2, 7]. Granulomatous necrotizing inflammation forms the morphological basis for tuberculous spondylitis and therefore it belongs to the group of primary chronic osteomyelites of the spine [1, 7].

The principal features of tuberculous spondylitis in children [3, 5] are as follows:

– predisposition of destructive process to the extensive involvement of several vertebrae with total or subtotal destruction of the vertebral bodies, leading to early formation of kyphosis and progressive deformity caused, among the other reasons, by continuing growth of the posterior spinal column [5, 11, 14]; deformity is the first clinical manifestation of the disease, which draws attention of child's parents;

– moderate pain; on the contrary, pain is a characteristic manifestation in adult patients;

– despite the deformity of the spinal canal and spinal cord compression with bone sequesters and abscesses, children rarely develop irreversible myeloischemic changes with severe neurological disorders, such as full plegia and pelvic disorders. High compensatory potential of the child's body lead to the fact that the manifestations of myelopathy in children are more prone to neurological improvement, when their causative factors are eliminated [5, 6];

– tuberculous spondylitis in children can develop both with and without compromising the immune system, either acquired (HIV) or primary (chronic granulomatous disease, interferon-gamma IL-12-related immunodeficiency, etc.) [1, 15]; morphological pattern of tuberculous lesions in patients with impaired immune response often differ from the conventional one due to incomplete phagocytosis and the absence of granulomas with central necrosis having typical cellular and tissue composition.

Diagnosis of the spinal tuberculosis in children

WHO recommendations (2011) suggest two diagnostic levels for extrapulmonary tuberculosis, including tuberculous spondylitis [4]:

– the diagnosis is considered as established, but not proven, when it is based on clinical, anamnestic, instrumental, radiographic, and laboratory data, but does not have bacteriological confirmation;

– proven diagnosis corresponds to the cases, where Mycobacterium tuberculosis was verified in the material obtained directly from the pathological lesion by cultural or molecular genetic bacteriological methods [8, 13].

Taking into account the different levels of availability of bacteriological diagnosis in the countries, where appropriate bacteriological examinations are not available, the diagnosis of "spine tuberculosis" is considered as proven on the basis

of clinical and radiographic data without bacteriological confirmation [13].

Specific skin tests, immunological and serological laboratory tests for tuberculosis are not the methods verifying specific disease of the vertebrae or its activity, their results cannot be used to confirm or exclude the specificity of a spondylopathy [13].

The principles of treatment of tuberculous spondylitis in children

Current treatment of tuberculous spondylitis in children combines a comprehensive antituberculous treatment and surgical treatment.

The effectiveness of the modern antituberculous chemotherapy directly depends on the use of drugs, to which mycobacteria are sensitive. Regimens (combination of drugs and duration) of chemotherapy are determined based on the drug sensitivity/resistance of mycobacteria. Abscess puncture or trepanobiopsy of the vertebral destruction area followed by bacteriological study of the bioptate, including bacterioscopy, culture in solid and liquid media, as well as detection of mycobacteria fragments (PCR) or mutations in the genes responsible for drug sensitivity are carried out in order to maximize early verification, which reduces verification time to several hours or days [4, 13]. Criteria of the efficacy of conservative treatment include elimination of paravertebral abscesses as evidenced by radiographic methods and signs of healing of bone destruction foci in the vertebrae.

Indications and methods of surgical treatment of spinal tuberculosis significantly differ in children with active tuberculosis and its consequences.

Surgical treatment of active tuberculous spondylitis in children. Complications of tuberculous spondylitis, including neurological (complete or incomplete paralysis, pelvic dysfunctions due to compression or tension of the spinal cord within the spinal canal caused by its deformity or epidural abscess) and orthopedic (spinal deformities and/or pain with underlying spine instability, which do not respond to orthoses) are the absolute indications for surgical treatment of active tuberculous spondylitis in children [9, 10, 16, 17]. Characteristic features of spinal deformity in children with tuberculous spondylitis are due to both extended destruction of the vertebral bodies, active growth of the posterior column of the spine, and predisposition of the tissue in the inflammation area to the development of scars during remission of tuberculosis. These reasons explain steady increase in the deformity accompanied by the development of severe rigid angular kyphosis, which cannot be corrected by means of external fixation neither during active process nor during remission and complete regeneration with formation of bone block. They can only be corrected using surgery. The most severe deformities develop when the vertebrae of the junctional zones are involved, such as cervicothoracic, thoracolumbar, as well as of the thoracic spine.

Ineffective intensive conservative treatment of patients initially having no neurological or orthopedic complications of spondylitis with antituberculous agents, as evidenced by preservation or progression of abscesses and destruction foci detected during the control radiographic (CT, MRI) study, is another absolute indication for surgical treatment. The lack of treatment efficacy may be due to multi-drug resistance of mycobacteria (MDR), including extensive resistance (eX-DR).

The objectives of surgical treatment of active tuberculous spondylitis in children include complete removal of pathological tissues (abscesses, destroyed vertebrae), elimination of spinal cord compression, restoration of the supporting ability of the spine, correction of its deformity, and creation of conditions for symmetrical growth of the anterior and posterior spinal columns. In most cases, these problems can be solved in one surgical session (operation under one anesthesia) through the combined approaches or posterior approach. The full-scale operation through a posterior-only approach is not possible due to the need for adequate viewing for the complete removal of pathological tissues and extended anterior fusion. This nessessitates the transsection of the spinal root (roots), which is relatively safe only at the thoracic level in the case of the limited length of spondylitis and minor kyphotic deformity. In the case of active spondylitis, correction of large kyphotic deformity through a posterior-only approach with subsequent shortening of the posterior spinal column (closed wedge osteotomy) is associated with high probability of corrugation of the dura mater and the risk of postoperative neurological complications. That is why combined approaches and stabilization methods, which enable simultaneous lengthening of the anterior spinal column and shortening of the posterior column, when necessary, are advisable in the surgical treatment of tuberculous spondylitis, especially complicated with severe (greater than 50°) spinal deformity in children. It should be borne in mind that deformity correction in children with tuberculous spondylitis provides not only cosmetic results, but also conditions for balanced growth of the anterior and posterior spinal columns, which is of fundamental importance for prevention of the secondary posttuberculous kyphosis.

The principal stages of the modern surgical treatment of active tuberculous spondylitis are as follows.

1. Resection of pathological tissue of abscesses and degraded vertebrae. Operation is carried out through the lateral and, when possible, extra-abdominal approach: thoracic – transthoracic extrapleural; thoracolumbar – thoraco-diaphragmal, lumbar – retroperitoneal, lumbosacral – ilioinguinal. Once abscesses are opened, their contents is removed, intact surfaces of the destroyed vertebral bodies are exposed, vertebral canal is opened, its pathological contents are removed and the dural sac is released.

2. Anterior stabilization of the spine. Complete removal of the pathological tissues is followed by test correction of the kyphosis using manual reclination or temporary interbody distractor in order to select the variant of the anterior fusion. If test correction cannot completely repair the deformity,

anterior fusion is carried out using bone grafts (autologous ribs, iliac wings, bone allografts) or combination of bone graft and supporting titanium meshes. The historical name of the combination of the complete removal of pathological tissues and anterior fusion in patients with spinal tuberculosis, "Hongkong surgery", is a tribute to Hodgson and Stock, who developed and widely used these operations in the mid-1950s, when working in Hong Kong.

3. Under current conditions, posterior instrumentation/fixation of the vertebral column is the main method for deformity correction and stabilization of the spine during extended reconstruction in children with tuberculous spondylitis. Instrumentation length should exceed the length of anterior reconstruction by 1–2 segments both in the cranial and caudal direction in order to provide stable instrumentation and prevent increase in the deformity. CD-instrumentation having low support element profile is used for polysegmental instrumentation in children. Structures with hook support elements are preferred in the polysegmental fixation of the spine in infants; transpedicular screws can be used in the end fixed vertebrae. Rods are designed with allowance for the sagittal spinal curvature being restored and are inserted into the support elements with a moderate effort, which is accompanied by deformity correction.

4. In the case of spinal deformities exceeding 50°, adequate correction of kyphosis is impossible without additional resection of the posterior spinal column. In these cases, the radical stage of the surgery if followed by mounting of support elements of the metal structure through the posterior approach without closing the lateral approach prior to the anterior fusion. Then, 1–2 arches with articular processes are removed at the apex of the kyphosis and instrumentation is carried out with apical compression. Typically, this results in arch contact or significant decrease in diastasis between them at the area of laminectomy [10]. Additionally, bone grafts are placed along the instrumentation zone in order to achieve formation of adequate bone block. Posterior instrumentation is followed by anterior stabilization using autologous bone with or without titanium mesh. Posterior wound is tightly sutured, approach to the vertebral bodies is drained with active aspiration device, typically for 1–2 days. Recent studies demonstrate that total reconstruction of the spine in the junctional zones is possible through the posterior approach only [16, 17].

5. In the case of cervico-thoracic spondylitis complicated by severe kyphosis, instrumentation in children is characterised by the use of connectable structures: after the separate fixation of cervical and thoracic spine and resection of the arch (or arches) at the apex of kyphosis (usually, T1 and/or T2 arches) cervical and thoracic rods are connected on each side with patient's head and cervical spine tilted. It is advisable to fix the head in the halo-ring or Mayfield frame during the operations and corrective manipulations in that area (Fig. 1).

In young children, posterior metal structures are removed no earlier than in 1–1.5 years after reconstructive surgery, when stable anterior spondylitis is formed as evidenced by radiographic methods (CT). Resorption of the grafts at the reconstruction area is usually indicative of recurrence or progression of spondylitis and requires repeated intervention, which can be done without dismounting the posterior metal structures. Formation of pseudarthrosis at the level of spine reconstruction and occurrence of seromas above the support elements of the structure are usually due to destabilization of the structure and necessitate repeated instrumentation.

Surgical treatment of the consequences of tuberculous spondylitis in children

Consequences of early childhood tuberculous spondylitis, especially after its surgical treatment in this period, are quite a specific pathology [12]. The deformities developing with underlying cured tuberculosis and active growth of a child can be either typical monoplanar or combined (kyphoscoliosis). At the same time, compensatory lordosis is observed in the adjacent segments, typically below the level of kyphosis. As a rule, the deformity gradually increases throughout the whole childhood and rapidly progresses during puberty due to the rapid growth of the skeleton. By the end of growth (16–18 years), the spine typically includes a bone conglomerate at the area of previous pathology and reconstruction. Progressive deformity and complaints of back pain during that period may be due to the lack of true bone block (pseudoarthrosis) at the area of reconstruction, as well as the development of instability in the segment contacting with the area previously subjected to fusion. Progressing deformity and growth of the spine are accompanied by typical deformity of the spinal canal, i.e. its extension in the anteroposterior direction and narrowing in the transverse direction. It is accompanied by changes in the local spinal blood flow: fibrotic changes in the paravertebral tissue and preceding surgical manipulation may result in reduction of segmental vessels, which increases the risk of myeloischemia both in the case of the natural course of post-tuberculosis deformity and its planned surgical repair.

Correction of post-tuberculosis spinal deformities is possible only through the circular reconstruction of the spine, the so-called 360° reconstruction of the wedge resection of the spine (Fig. 2–3) and belongs to operations with a high risk of postoperative myeloischemia.

It is a single-stage operation performed through the posterior approach using successive steps of mobilization, temporary instrumented fixation, vertebrotomy, instrumented correction, final instrumented fixation, and osteoplastic stabilization [9, 10]. The operation is necessarily accompanied by neurophysiological monitoring of evoked potentials and wake-up test.

Pre-planning of the extent of spine resection and instrumentation length is carried out based on X-ray and CT examinations, the condition of the spinal cord is controlled using the MRI. Vertebral arches are exposed through the posterior approach and usually represent a single bone conglomerate. At the level of planned resection, transverse processes are resected from two sides in the opposite directions,

and, in the thoracic region, rib heads adjacent to vertebrae are resected, while preserving the pleura. If vascularized rib periosteum was used for the previous primary reconstruction of the spine (this operation was popular in 1980—1990s), the bone bridge extending from the ribs to the vertebrae should be resected. Thereafter, raspatories are used to separate the anterior longitudinal ligament from the lateral one up to the anterior surface. Transpedicular screws are installed into the supporting vertebrae (preferably at least two or three levels above and below the resection area, taking into account the upper level of fixation) and temporary fixing rod is placed on the one side in order to prevent spontaneous displacement of the vertebrae during the vertebrotomy with allowance for the planned length of the instrumented fixation. The upper level of instrumentation should not end at the level of physiological kyphosis. Posterior decompression of the spinal canal is carried out followed by the wedge vertebrotomy with circular release of the dural sac. When visually determined mobility of the segments is achieved, the rod is mounted at the level of vertebrotomy on the contralateral side. Then the deformity is corrected by means of step-by-step alternating pressure and structure modeling on both sides, which is accompanied by approximation or contact of the vertebral bodies. Residual post-laminectomy defect is overlapped with bone grafts.

If spinal nerve conduction disorders are detected during the neurophysiological monitoring, instrumented correction is stopped, correcting pressure of the structures is reduced to restore evoked potentials and wake-up test is carried out. Instrumentation is performed without complete correction and pharmaceutical protection of neural structures is carried out by administration of vascular drugs and glucocorticoid hormones.

Treatment of post-tuberculous spinal deformities complicated by prolonged (more than 1.5—2 years) severe neurological disorders (full plegia) and contractures of the lower extremities differs from the aforementioned one. In these cases, changes in the spinal cord typically detected by MRI (atrophy, myelomalacia) give no hope of the recovery of spinal cord function after surgery. Spinal surgery may be indicated for improvement of patient's social adaptation and nursing process. This is achieved by instrumented fixation of the spine over a large area, wherein vertebrotomy is used to provide more advantageous position of patient's body for sitting and using a wheelchair.

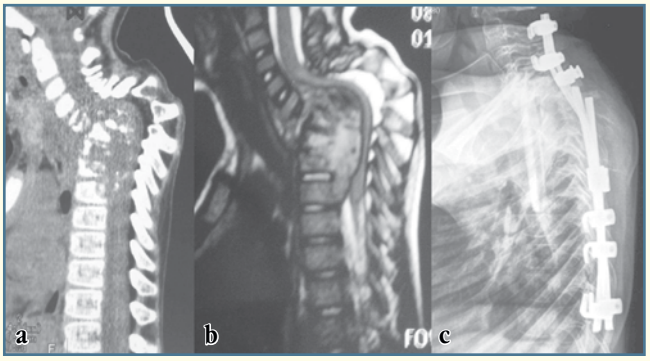

Fig. 1
Active tuberculous spondylitis at C5–T8 in a 4-year-old child. CT **(a)** and MRI **(b)** show extensive destruction of the vertebral bodies, including total destruction at C6–T4, subtotal destruction at T5, and focal lesions at T6–T8 bodies with large epidural and prevertebral abscess. Despite the severe deformity and compression of the spinal cord over a large area, neurological disorders corresponded to type D on the Frankel scale; the operation was performed through two approaches: abscess removal, C5–T6 resection, and T7–T8 necrectomy were carried out through the posterolateral transthoracic approach through the bed of the 3rd rib; T1–T2 arch was resected through the posterior approach with C2–T9 instrumentation and kyphosis correction **(c)**; the operation was completed by anterior fusion with cortical allobone through the basic transthoracic approach. The early postoperative period was characterized by increase in neurological disorders to type C on the Frankel scale followed by complete regression to type E within 2 months after the operation

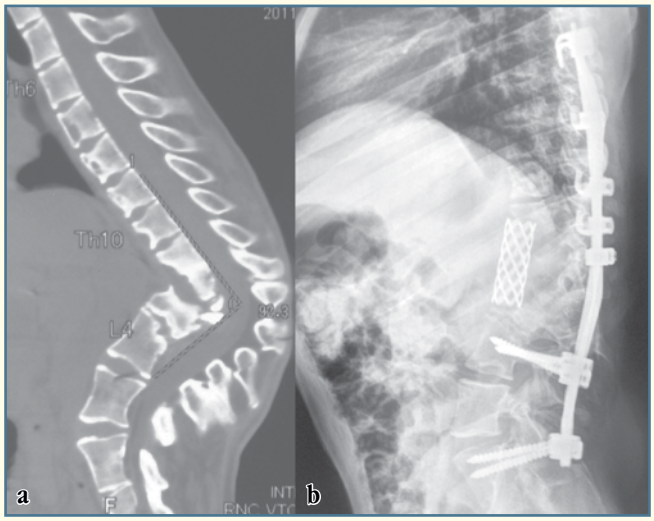

Fig. 2
Inactive tuberculous spondylitis (remission) at T7–T8, T11–L3 in a 16-year-old adolescent. Paravertebral abscess was opened at the age of 6 years. Tuberculosis treatment resulted in remissions of active spondylitis, however, severe kyphotic deformity was formed accompanied by pain syndrome **(a)**, but without neurological disorders. Spine reconstruction was carried out through two approaches including the anterior stabilization with mesh and autologous bone **(b)**; during the operation, caseous masses were observed in the ruined vertebral bodies; posterior instrumented fixation was carried out using hybrid variant of instrumentation (hooks and transpedicular screws) because of residual destructive cavities in the inferior thoracic vertebrae. Postoperative period was uneventful; long-term outcome was followed for 4 years

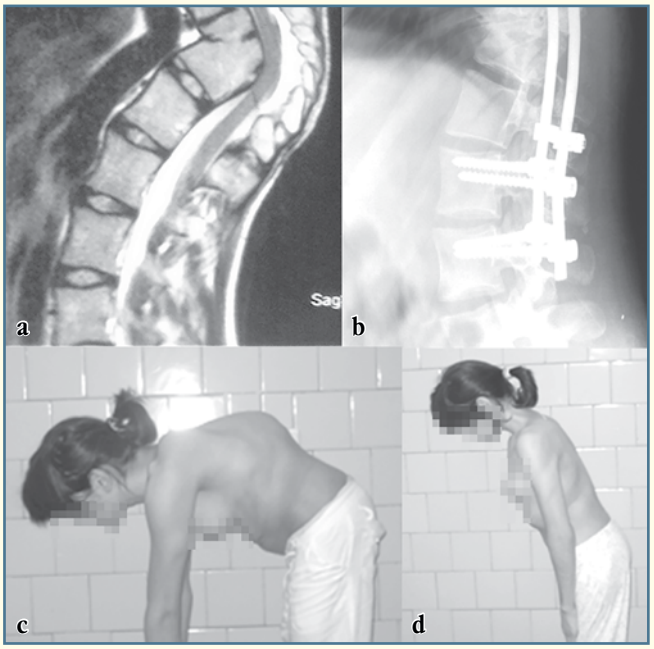

Fig. 3
The consequences of the tuberculous spondylitis at T9–L1 in a 15-year-old child. Radical surgery (Hongkong surgery) was carried out at the age of 3 years, solid bone block was formed **(a)**. At the age of 13 years, the patient began to complain of increasing spine deformity and pain in the lumbar region **(b, c)**; wedge osteotomy was carried out from the posterior approach with instrumented fixation of the spine **(d)** with good cosmetic effect and elimination of pain syndrome. The outcome was followed for 4 years. The patients has an active lifestyle and no subjective complaints

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