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Experimental spinal surgery and neurosurgery at the Russian Ilizarov Scientific Center "Restorative Traumatology and Orthopaedics"

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The authors describe major trends and developments of experimental spinal surgery and neurosurgery at the Russian Ilizarov Scientific Center "Restorative Traumatology and Orthopaedics".
Keywords: experiment, spinal surgery, neurosurgery, spine, spinal cord, scoliosis, spondylodesis, trauma

Modern spine surgery has made major advancements in both techniques and spinal instrumentations over the past decades that allow for accurate diagnosis and timely treatment of various conditions of the vertebral column.

The staff of the Russian Ilizarov Scientific Center "Restorative Traumatology and Orthopaedics" (RISC "RTO") has made significant contributions to the advancement of spinal surgery through experimental research of transosseous osteosynthesis applied to spinal procedures [1–3].

Specific aspects of human and canine blood supply to the spinal column, and unilaterally and bilaterally impaired circulation leading to spinal deformities were studied at the beginning of the work [4, 5]. Unilateral long-standing ischemia was shown to result in a fixed grade I to II scoliotic or kyphotic curve. No spinal deformity was observed to develop with bilateral symmetrical blood supply insufficiency [4, 6–8].

Further investigation included techniques devised to correct spinal deformities. Damage to arterial blood supply at a convex side of scoliotic curve resulted in either a regression of the deformity signs or discontinuous progression. The realignment of the vertebral column was a gradual process within 4 to 6 months with no need for additional interventions [9]. The findings suggested that changes in blood supply could be considered as one of major factors affecting bone formation [4].

Spinal fixation techniques and devices were concurrently developed and improved at the experimental department. Topographical and anatomical investigations revealed specific aspects of spinal structures in a variety of experimental animals with safe areas and directions identified for wire and half-pin placement [10–13]. Stable controlled vertebral fixation could be provided with constructs offered [14].

Apart from other authors, an external transpedicular fixation device was pioneered in 1982 for human spine [15]. Biomodel and biomechanical testing eventually proved the possibility with controlled, stable and safe spinal fixation that was introduced into clinical practice and widely used by the staff of neurosurgery department, the RISC "RTO" [16–26].

Experimental studies showed the disturbed balance of static and dynamic loading being important for pathogenesis of spinal deformities. Simulated asymmetric loading on the spine with external fixation device resulted in static grades I and II scoliosis. Structural changes developed in vertebrae and intervertebral discs and spread to other spinal motion segments of major and compensatory curves [4, 27].

Later a variety of techniques were offered to simulate scoliosis in animals with incomplete spinal growth including osteotomy of dorsal structures and epiphysiolysis of adjacent vertebrae with external spinal fixation followed by gradual bone angulation and rotation; endoscopic coagulation of spinal ganglia; stapling of adjacent vertebrae with thermochemical shape memory clamps with/without an implant additionally placed in the subchondral bone of the vertebral growth zone [28–36].

There were several experiments conducted to increase the shape and size of vertebral structures [37]. Either transverse or longitudinal traction was applied in lumbar and thoracic spine of adult animals using external fixation device. Transverse traction resulted in gradual increase in the radius of the curve and length of the vertebral body located at the apex of an arch formed (up to 30 % of the original magnitude). Sagittal and coronal sizes of the vertebral body were noted to increase at a later stage. Longitudinal traction with tense muscles facilitated the growth of spinous processes at the traction area [38].

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Vertebral lengthening technique was devised in animals with incomplete growth using epiphysiolysis followed by longitudinal epiphyseal distraction. Vertebral lengthening occurred with regenerate bone formed at the gap site between vertebral body and cranial/caudal growth plate and reached 70 % of the original length. Each of two adjacent vertebrae was lengthened by 30 % at acute epiphysiolysis [39, 40].

Transverse osteotomy was performed for vertebral animals in animals at skeletal maturity. The increase in craniocaudal vertebral sizes up to 100 % persisted at long-term follow-up [40, 41]. Subsequent vertebral lengthening resulted in local stretching of the spinal cord and paraplegia of pelvic limbs [42].

Similar principles were used to increase coronal (by 20 %) and sagittal (by 90 %) sizes of the spinal canal as well as dorsoventral and craniocaudal (up to 100 % of the original length) sizes of intervertebral foramen [43–47].

A lot of research was done to simulate and repair injuries to spinal column studying reparative osteogenesis at different types of spinal trauma (compression, stable, unstable penetrating, etc.). Stable external fixation of the spine was shown to provide optimal mechanobiological conditions facilitating reduced length of vertebral regeneration restoration of the integrity [48–52]. A penetrating fracture of a vertebral body led to evident degenerative changes of an injured intervertebral disc (deformity, ruptured and dissociated laminae of annulus fibrosus, Schmorl's nodes) even at stable external fixation that indicated to a need of a radical reconstruction of an injured spinal motion segment [50, 53].

A series of experiments aimed at new techniques of stabilizing spinal procedure was conducted to simulate spondylodesis without grafting. One of the first techniques included spondylodesis by concurrent mechanical impact on ventral surface of intervertebral disk and dorsal surface of articular processes of adjacent vertebrae with polyethyleneterephthalate band [4].

A later technique of ventral spondylodesis included vertebral fixation with the Ilizarov apparatus, wedge-shaped discectomy followed by gradual distraction and wedge-shaped bone regeneration to replace the excised disk [54–56]. A separate series included transverse osteotomy of a vertebral arch additionally produced at the base of symmetrical articular processes forming the joints to prevent degeneration of facet joints located at excised disc projection [57]. These techniques of spondylodesis ensured interbody fusion formed as a bone block structured in the way as bodies of the stabilized vertebrae, or fibrous-cartilage block being stable to static and dynamic loadings [58].

Techniques of dorsal spondylodesis were developed to replace articular processes of adjacent vertebrae with either distractional regenerate bone or fused facet joints [59, 60].

One of experimental lines studied effect of a local injury to the spinal cord on spinal shape. The findings suggested that a partial lateral transverse dissection of the spinal cord at lumbar spine resulted in scoliotic curve at early postoperative period with concavity at the injury side and magnitude depending on an area of the spinal cord injury. Scoliotic curve increased at a later phase with rotated vertebrae and oblique pelvis. Concurrent flattening of lumbar spine lordosis was observed with formation of kyphosis to follow. In addition to that scoliosis appeared spontaneously corrected in several dogs [61].

Biomechanical simulation demonstrated that targeted deformity of the vertebral column provided maximal approximation of partially dissected spinal cord wound surfaces. A curve in the sagittal plane was to be increased to get hyperlordosis with dorsal injury to the spinal cord at the level of cervical or lumbar spine; this part of the vertebral column was stabilized at the thoracic spine in neutral physiological position with concurrent simulation of kyphosis at lumbar spine. Lateral injury of the spinal cord required additional lateral flexion at the side of diastasis [62–65].

The research was done to study continuous compression of the spinal cord simulated with polyethyleneterephthalate 5 mm band. Morphological findings showed growing destruction of nervous tissue, adhesion of meninges, spinal cord and the adjoining bone tissue, as well as irreversible changes of its shape [66].

In recent years, technical facilities for simulating contusion injury to the spinal cord of different severity and techniques to eliminate and prevent postoperative complications have been developed and tested in small laboratory animals [67]. A technique and hardware have been offered to study penetrance of the spinal cord meninges in laboratory animals [68].

At the present time the experimental studies have become the theoretical foundation for further development of spine surgery.

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