SPINOPELVIC FIXATION: INDICATIONS, ANATOMICAL AND BIOMECHANICAL ASPECTS AND HISTORICAL DEVELOPMENT OF METHODS

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A review of the literature on performing spinopelvic fixation for injuries and various pathologies of the spine and pelvis is presented. The review is analytical in nature and was carried out using databases of medical literature and search resources of PubMed and eLibrary. The following aspects are highlighted: the relevance and indications for performing spinopelvic fixation and its anatomical and biomechanical features. The historical aspects of the development of methods for performing spinopelvic fixation are considered and structured. The analysis of various methods of spinopelvic fixation (using hooks, screw insertion into the S2 sacral wings, L-shaped Luque rods, distractors, transiliac rods, Jackson, Harrington and Galveston techniques) was carried out. The features of surgical techniques, their advantages, disadvantages and complications are considered.

Key Words: spinopelvic fixation, lumbosacral spine, spinal deformity.

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Spinopelvic fixation is becoming increasingly important in spine surgery. If earlier the main indications for its use were deformities associated with pelvic torsion (neuromuscular scoliosis), then with the expansion of surgical activity, an increase in the number of spinal osteotomies, sagittal balance correction of the trunk, the question of performing spinopelvic fixation has acquired a new significance. The anatomic features of the lumbosacral spine as a transitional zone, complex biomechanical interactions, as well as its crucial role for the entire axial skeleton define the relevance of the spinopelvic fixation performance.

This paper presents the first part of the literature review on spinopelvic fixation. The search is performed in the PubMed and eLibrary databases.

The objective is to analyze features of anatomy and biomechanics of the lumbosacral spine in relation to spinopelvic fixation, to identify the main indications for its implementation, to present techniques of spinopelvic fixation, their characteristics, advantages and disadvantages.

The first part of the article discusses techniques that are already of historical interest. Nevertheless, some of them are implemented and developed at the current stage of spine surgery.

Anatomical and Biomechanical Features of Spinopelvic Fixation

Lumbosacral junction is one of the so-called transitional zones of the spine. It makes the transition from a relatively mobile lumbar spine to a rigid pelvic ring. After that, there is a further redistribution of the load to the lower limb girdle. The biomechanics of this segment is complex. It is driven by a number of human traits, including his postural characteristics and upright posture. The exercise stress on the lumbosacral spine is extremely high. The force effects passing through the lumbosacral junction includes an axial load. It is almost 3 times higher than the body weight during physical exertion. In everyday activity, this area is exposed to the shear load caused by the anatomy of the lumbosacral spine and lumbo-pelvic interrelation, including lumbar lordosis, pelvic incidence (PI) and others, and also the complex loads that arise during flexion, extension and rotation of the trunk. In forward inclination of body, the lumbosacral spine suffers shear loads of up to 100 N [1].

The sacrum is composed mainly of spongy bone tissue with a relatively thin cortical box. The S1 pedicles are wide and, regardless of the shape of the screws used, are not in close contact with the tubular bone, which downgrades the strength of their fixation. The small anterior-posterior size of the sacrum limits the length of the screws used [2, 3]. If osteoporosis is present, it significantly lowers the fixation strength of the screws in the sacrum.

Therefore, the difficulty in achieving stable fixation of the lumbosacral spine is related both to the unique features of this anatomical area and to the high biomechanical loads on it.

We consider the so-called short fixation involving one or more caudal segments of the lumbar spine and sacrum (lumbosacral fixation) up to the S1 vertebra, also to a certain extent a type of spinopelvic fixation. It is anatomically and biomechanically justified to consider

the sacrum as a part of the pelvis. The experience gained in the use of extended fixation up to the L1 vertebra and cranially defines the relevance of additional spinopelvic fixation, the use of more reliable instrumentation techniques and spinal fusion.

In 1992, McCord et al. [4] performed a biomechanical study on cattle spinal segments and assessed 10 techniques of spinopelvic fixation. By analogy with the lever system, McCord introduced the concept of a "pivot point" in the lumbosacral joint. The authors believe that the pivot point of the lumbosacral spine is located in the so-called middle osteoligametous column between the L5 and S1 vertebrae. The middle osteoligametous column, in turn, is represented by the posterior vertebral bodies of L5 and S1 and the posterior annulus fibrosus with a part of the posterior longitudinal ligament (Fig. 1).

According to the obtained data, the more anteriorly the fixator is located from the pivot point, the stronger the fixation (Fig. 2). The strongest fixation was identified when using screws or rods installed in the iliac bones. The authors also concluded that the installation of screws through the sacroiliac joint is meaningful only if they are of sufficient length. They should be located anteriorly to the pivot point. In turn, the use of Harrington and Lugue techniques for spinopelvic fixation is not justified due to insufficient strength.

O'Brien [5] identified 3 fixation zones in the sacropelvic segment (Fig. 2): I – S1 vertebral body, cranial parts of the sacral wings; II – lower parts of the sacral wings, sacrum from S2 to coccyx; III – iliac bones on both sides. He notes that the fixation strength increases from zone I to zone III. Zone III has the highest mechanical strength during the pull-out test and during flexion-extension. Additionally, the location of the screws or rods in the iliac bones, i.e., in the most stable fixation zone, allows the implants to be placed much more anteriorly from the McCord pivot point, which also enhances the fixation stability.

Indications for Spinopelvic Fixation

There are several main indications for spinopelvic fixation [7–12].

1. Prolonged instrumental fixation of the spine involving the sacrum. It is the most frequent indication for spinopelvic fixation. During extended fixation involving the sacrum, an extremely high flexion load arises, aggravated by the lever effect at the lumbosacral joint (Fig. 3) [9]. Cunningham et al. [13] demonstrated that fixation above the L3 vertebra significantly increases the load on the screws in the S1 vertebra. The strengthening of the distal part of the fixation by iliac screws decreases the load on the screws in the S1 vertebra. The proximal fixation point, which would be an indication for spinopelvic fixation, is not clearly identified. According to some authors, spinopelvic fixation should be performed if the instrumentation is performed from the S1 to L2 and above. According to others – if above the level of the thoracolumbar junction [14–16].

2. Correction of lumbosacral deformities. Severe deformities followed by sagittal and frontal imbalance often require three-column osteotomies, which results in destabilization. In this case, spinopelvic fixation ensures, in fact, adequate spine stability [17–19]. Additionally, there is an additional leverage when correcting spinal deformity and pelvic torsion.

3. Surgical treatment of severe spondylolisthesis. Analysis of the treatment outcomes of 3–4 grade spondylolisthesis revealed a high level of destabilization of fixation at the S1 vertebra with reduction loss, if the posterior instrumental fixation is not complemented by spinopelvic fixation [20, 21]. Biomechanical and clinical studies have shown that spinopelvic fixation in severe grades of spondylolisthesis ameliorates the treatment outcomes and downgrades the complication rate [22–24].

4. The correction of neuromuscular deformities followed by a pronounced pelvic torsion. The application of fixing elements only up to the sacrum does not ensure proper stabilization or sufficient leverage for corrective maneuvers in neuromuscular scoliosis with pronounced pelvic torsion [25–27].

5. Fractures of the sacrum and pelvis with the manifestation of lumbopelvic dissociation. Spinopelvic fixation in such cases permits both to achieve stable fixation with the elimination of instability

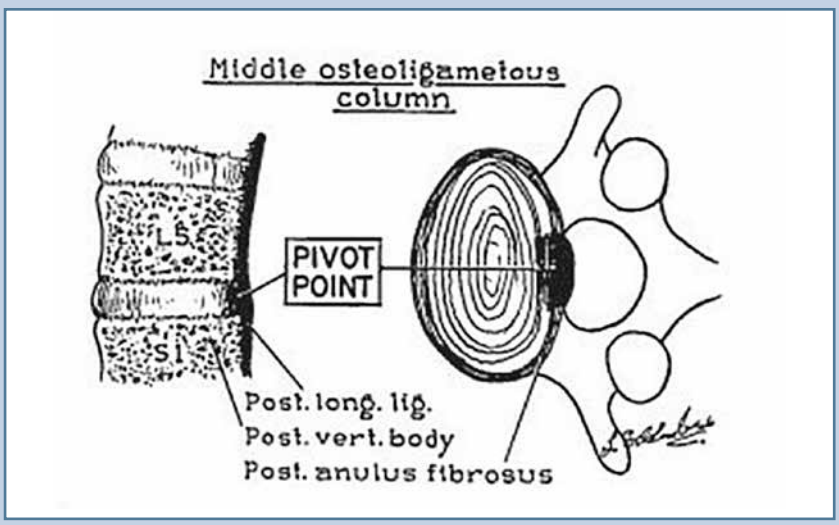

Fig. 1
The pivot point of the lumbosacral spine according to McCord et al. [4]

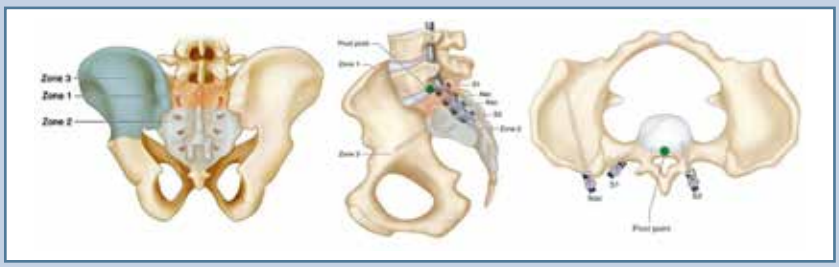

Fig. 2
The location of the implants relative to the McCord pivot point [6]

and pain syndrome, and to perform the apposition of bone fragments [28–30].

6. Bone defects of L5, S1 as a result of tumor, inflammatory or other destructive processes.

7. Oncological surgeries requiring partial or complete resection of the sacrum.

8. Unsatisfactory outcomes of previously performed surgeries: pseudoarthrosis at the L5–S1 fixation level, fractures and instability of surgical hardware, osteoporosis [12].

Techniques for Spinopelvic Fixation

Spinal fusion in situ. The spinopelvic fixation until the 60s of the last century was reduced to spinal fusion with bone grafting *in situ*, which needed prolonged brace immobilization. Nevertheless, the frequency of bone block formation failure was extremely high. It was observed in more than 50 % of cases [31]. The poor results were a strong incentive to the development and implementation of various fixators that could reduce the need for long-term loads limitation and improve the ossification.

The Harrington technique of spinopelvic fixation. It was Harrington [32] who in the 60s of the 20th century developed the first widely used instrumental system for the scoliosis correction. It consisted of rods and hooks to enable contraction and distraction. The hooks were anchored in the arch or transverse processes. It was also possible to focus on the arches of the S1 vertebra, thereby performing spinopelvic fixation. However, this technique was associated with a huge number of instability cases. For improving the outcomes of spinopelvic fixation, Harrington proposed the application of a special transverse sacral rod. The technique consisted of installing threaded rod in iliac wings through two additional incisions. The rod was stabilized by tightening with nuts. Then the distal ends of the Harrington distractors were attached to it. However, this did not allow to avoid a high frequency of unsatisfactory results. These included up to 40% of pseudoarthrosis of the lumbosacral segment and 26 % of hook instability [31]. The Harrington instrumentation also did not have sufficient stability during flexion and rotation, as well as leaning laterally [31, 33]. Additionally, due to a decrease in lumbar lordosis, it resulted in the flat back syndrome [31, 34].

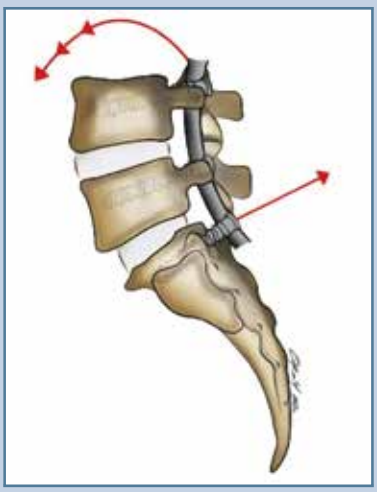

Fig. 3
The load pulling out the screws in the S1 vertebra when the trunk is pitches forward [10]

Kazmin's distractor. Beginning in the 60s of the last century, A.I. Kazmin applied the technique of scoliotic deformity correction with the help of an original distractor [34]. The lumbar scoliotic curve was corrected using distractors, which bumped distally into the iliac crest, proximally into the transverse process of the vertebra. We believe that this technique can be legitimately attributed to spinopelvic fixation. This is supported by the fact that the technique is applied in the spondylolisthesis treatment, as well as after sacral tumor resection (Fig. 4) [35]. The distractors did not have the ability of primary rigid fixation. This was primarily related to the lack of rotational stability. It required a long period of loads limitation in the form of bed rest and rigid bracing before the bone block formation. But at that time, the use of distractors allowed to significantly improve the treatment outcomes of spinal deformities. The distractions have become redundant only with the introduction of segmental fixation of the spine and TPF.

Fixation by L-shaped Luque rods. An essential stage in the instrumental fixation of the spine, including the implementation of spinopelvic fixation, was the technique proposed by Luque. The technique was developed in the 70s of the 20th century; the first papers were published in the 80s [36–38]. The concept of segmental fixation of the spine was firstly introduced by the Luque system. The rods were fixed by a sublaminar wire. Therefore, there was a possibility of direct multilevel impact on the spine segments. This technique differed from the direct impact only on the cranial and caudal hooks when using distractors. The instrumentation enabled contouring and thereby correction to be done not only in one plane, providing an opportunity to preserve lumbar lordosis [14, 31]. In order to perform spinopelvic fixation, it was suggested to bend the rods at the distal end almost at a right angle and insert their short part into the

iliac bones, similar to the Harrington rod [36, 38]. King et al. [39] later modified the design for spinopelvic fixation, adding the option of fixing the rods inserted into the iliac crests by bolts (Fig. 5). However, this design was not ideal from a biomechanical point of view. The rods were not connected to each other, and thus there were piston-like movements. There was also a comparatively low stability of the structure with respect to torsion and flexion loads [33, 40]. Generally, the level of pseudoarthrosis with the Luque instrumentation was lower than with the Harrington one (6 vs. 41 %) [15, 41–43]. It should be noted that the damage to the roots during wire conduction is one of the complications [15].

Galveston technique. In 1982, Allen and Ferguson, who worked at the Texas Medical University in Galveston and collaborated with Luque, offered an original technique for pelvic fixation [44]. The new concept was the introduction of modeled rods through the posterior superior iliac spine into the iliac bones towards the large sciatic notch on both sides (Fig. 6).

After that, the rods were fixed to the lumbar and thoracic spine using a sublaminar wire. The implementation of the Galveston technique in the 80s of the last century considerably improved the surgical outcomes for extended fixations with spinopelvic fixation and decreased the incidence of pseudoarthrosis [41, 46]. One of the disadvantages of the Galveston technique is the micromotion of the rods in the iliac bones, which, along with the stress on them after deformation correction, according to a number of authors, results in the osseous resorption. The so-called wiper effect occurs [27] with subsequent destabilization [27, 47]. It must also be mentioned that the correct flexing of the rods is technically not an easy task. This challenge was solved in due time by the release of a line of precurved rods, which, being connected to each other in the proximal part, eliminated the need to install a framing spacer. Nevertheless, many surgeons simply cut off the upper joint of the rods, rationalizing this by the need for an accurate adjustment of the rod length [9]. There are reports of the high efficiency of the suggested technique of spinopelvic fixation: according to a number of authors, a bone block was formed in 88.0–93.7 % of cases [27, 46, 48]. However, some authors have also reported that the use of this technique results in a greater incidence of pseudoarthrosis in adult patients with deformities compared to patients with neuromuscular scoliosis [49]. The technique, also known as Luque – Galveston, has long been regarded as the gold standard in the treatment of spinal deformities with pelvic distortion. Up to now, this method is applied in a number of hospitals. The very idea of conducting rods into the iliac bones and using the latter as a fixation area and support was an advance in the development of techniques for spinopelvic fixation. There is no doubt that this idea resulted in the further appearance of transiliac screws installation technique.

Cotrel – Dubousset instrumentation. Introduced in the 80s by Cotrel and Dubousset, the system continued the principles of segmental fixation and correction of deformities. It included locking hooks and monoaxial screws [50, 51]. In addition to the possibility of a more stable fixation compared to the wire, as well as the opportunity for correction, including the technique of derotation in scoliosis, this system allowed for spinopelvic fixation. The performance of spinopelvic fixation only with screws or hooks that are fixed behind the S1 vertebra demonstrated low efficiency. The incidence of pseudoarthrosis reached 30–40 %, and complications associated with implants – up to 70 % [40]. The screw removal from the S1 vertebra reached 44 % [52]. Nevertheless, the Cotrel – Dubousset system has been greatly developed with the improvement of tools, procedures for the application and introduction of additional elements, in particular for spinopelvic fixation.

Fixation with hooks. The laminar hooks can be used to fix the instrumentation behind the sacrum. There are two ways of positioning the hooks, both caudally and cranially, and they are located in the intervertebral foramen of S1, S2 and S3. The hooks can be arranged in the form of a crab grip or as an addition to the screws transmitted in the S1 vertebra. Stovall et al. [53] demonstrated that the use of hooks in addition to fixing with screws in the S1 vertebra increases stability. However, it is known that lumbosacral fixation with hooks and sublaminar

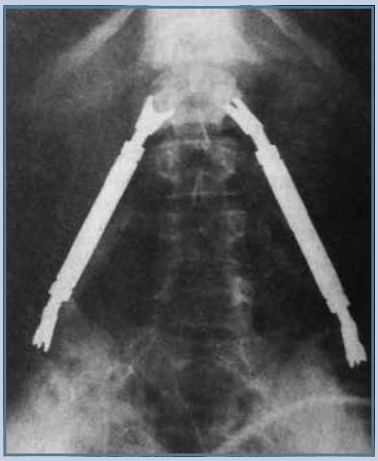

Fig. 4
The use of A.I. Kazmin's distractor for spinopelvic fixation after sacral chordoma resection [35]

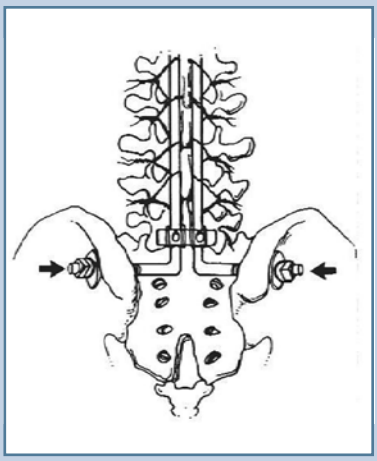

Fig. 5
Spinopelvic fixation with L-shaped rods in the modification of King et al. [39]

wire does not ensure sufficient stabilization and resistance to rotational and flexion loads [8, 34, 49]. Therefore, the use of hooks can only be regarded as an additional option to fixing with screws.

Jackson technique. In 1993, Jackson and McManus [54] studied the anatomy of the sacrum according to CT scans. They argued for the possibility of installing rods in the lateral mass of the sacrum when performing spinopelvic fixation (Fig. 7). In theory, the advantages of such fixation were the following: good resistance to the loads occurring when the trunk is tilted forward, and the absence of involvement in the sacroiliac articulation fixation. Nevertheless, technically there is a rather complicated contouring of the rods for inserting them into the sacrum and laying them into the screws inserted into the S1 vertebra. Additionally, there are doubts concerning the fixation stability in osteoporosis. There are also contradictory biomechanical studies of fixation stability by this technique [55, 56]. Nevertheless, there are reports of the successful application of this technique in the surgical correction of scoliosis in children [57]. In 2014, Fukuda et al. [58] have described a modification of the Jackson technique with the use of intrasacral insertion of polyaxial screws. It resulted in avoiding the complexity of contouring and installation of the rod.

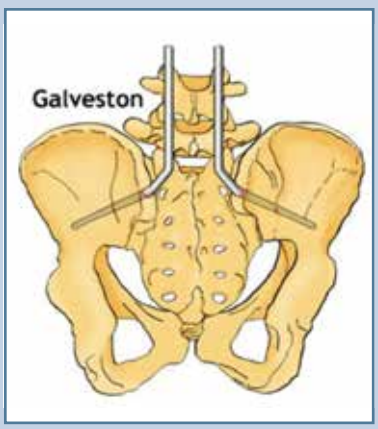

Fig. 6
Luque – Galveston spinopelvic fixation [45]

Dunn – McCarthy technique. It is especially difficult to implement corrective deformities in children with early development of scoliosis, having severe congenital deformities of the spine. McCarthy et al. [59], noting that in neuromuscular deformities, the iliac bones are often thinned, they suggested using a specially curved rod with its resting against the sacrum wings (Fig. 8).

The authors have published an article on the analysis of the surgical outcomes of 24 patients with neuromuscular scoliosis using Luque fixation and the resting of a curved rod against the sacral wings [59]. This technique of supporting of rods by iliac wings is still topical. It is used in the treatment of children with severe congenital spine deformities [61, 62]. The main complications of this pelvic fixation technique are the possibility of the S-shaped end of the rod sliding laterally or medially along the iliac crest, the development of the inflammatory process and the pain. Walick et al. [63], after performing a retrospective analysis of data on 49 patients treated using the Dunn – McCarthy technique, report the neuropathic pain in the leg in 14 % of cases due to irritation of the L5 root by the medially located intrapelvic rod end. Ramirez et al. [64] performed a multicenter study and studied the results of the use of VEPTR with spinopelvic fixation with a Dunn – McCarthy rod in 65 patients suffering from infantile scoliosis. The above-described complications were identified in 50 % of cases, to which fractures of the distal part of the structure and its instability were added [64]. The authors emphasize that the use of this instrumentation is justified in the treatment of progressive infantile scoliosis in the absence of another possibility of spinopelvic fixation. The number of complications is related not only to the severity of clinical manifestations, but also to the placement of the S-shaped hook. According to the authors, the support of the S-shaped rod end according to Dunn – McCarthy should be made within the middle third of the iliac crest (Fig. 9).

Warner and Fackler [65] modified the Dunn – McCarthy fixation technique for the treatment of children with kyphotic deformities associated with myelodysplasia. After giving a Z-shape to the distal end of rod, they led it through the first posterior sacral foramina, then through the sacral canal and the anterior sacral foramina. The support obtained in this way allowed the rod to be effectively used as a lever and to correct kyphotic deformity. Odent et al. [66] published the papers of using modified Dunn – McCarthy rods for the correction of severe kyphotic deformities in children with meningomyelocele in the second stage, the authors made an extended anterior spinal fusion.

Fixation with screws to the sacral wings, iliac bones and S2 vertebra. Anchorage to the sacrum, in addition to the screws in S1, can be the installation of screws in the sacral wings. The screws are inserted outward into the sacral wings and can be connected to the rod mounted above and onto the screws in the S1 vertebra through the sacral plates, Chopin blocks. According to biomechanical studies, lumbosacral fixation, combining divergently directed screws in the S1 vertebra, sacral wings and iliac wings, significantly outperforms fixation with screws only in the S1 vertebra [67]. A biomechanical comparison of spinopelvic fixation by Luque – Galveston and using Chopin blocks showed similar fixation strength by both techniques [68]. It must be noted that the use of plates imposes some restrictions on the choice of the screw insertion point and their direction. Another disadvantage is that the spongy bone tissue of the sacral wings is weak for fixing the screw. A bicortical screw is also available. However, it is not recommended, since the L5 nerve root and common iliac veins and arteries are located on both sides of the anterior surface of the sacral wings, and consequently there is a high probability of their injury [3]. An additional technique for strengthening the fixation to the S1 vertebra is the insertion of screws in S2. The pedicle of the S2 vertebra is short, and, probably, fixation is done to a greater extent due to the posterior vertebral cortical rim. A bicortical insertion is hazardous by damage to the large

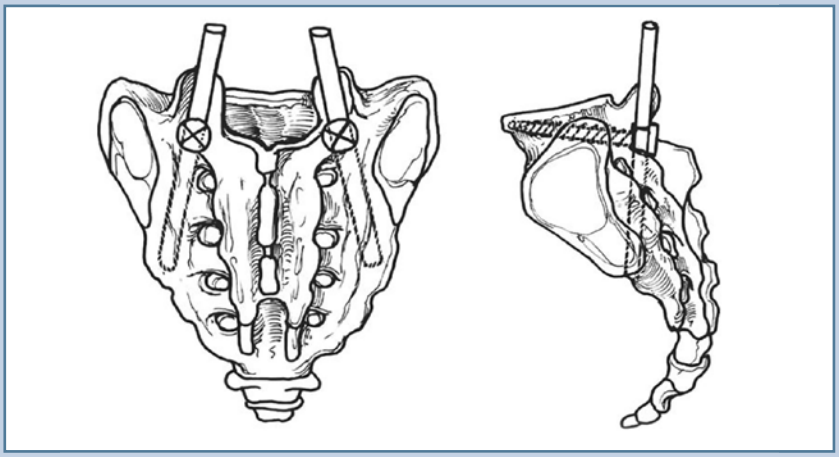

Fig. 7
Jackson technique of lumbosacral fixation with rods [54]

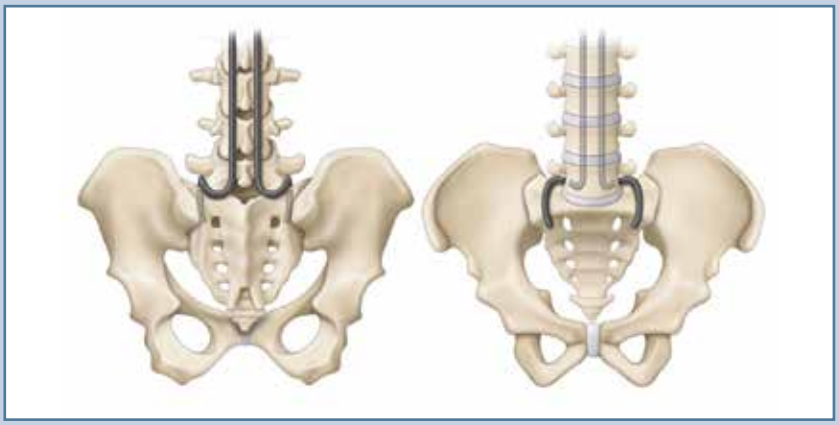

Fig. 8
Dunn – McCarthy technique of lumbosacral fixation with rods [60]

intestine. It has been biomechanically proven that a greater degree of fixation is obtained with the diverging direction of the screws [69].

Park et al. [70] suggested a diagonal screw insertion technique into the S2 vertebra and, in fact, into the sacral wings. In 2013, the authors published the results of using this technique in 13 patients with extended lumbosacral fixation. All but one of the patients had good results in the long-term period averaging 26.6 months. The insertion of the screws from the bottom up and laterally into the sacral wings allowed the use of relatively long screws (50 mm, diameter 6.0 mm). In order to prevent possible complications, the screws were transmitted in monocortical manner. The authors suggest their technique as an alternative to iliac screws, which, of course, is of interest. However, it requires more studies.

Transiliac fixation. The concept of Harrington with a transverse rod transmitted through the iliac bones was further developed. Widmann and Hresko [71] suggested their modification of the Harrington transiliac rod, using additional fixation with transverse connecting beams and connectors from the Cotrel – Dubousset system. The authors used the technique in 10 children and adolescents with neurogenic and congenital deformities and observed its effectiveness. No more papers on this technique have been found.

Kostik [72, 73] proposed using a rod without a thread, unlike Harrington, which could be installed without additional incisions. The rod was contoured along the surface of the sacrum, attached to the screws in the S1 vertebra and connected to the superposed structure. Kostuik [73] points out that anterior L5–S1 fusion is required to achieve sufficient stability. Despite the high efficiency of the technique described by the author with the fusion formation in 97 % of cases [73], no articles analyzing the outcomes on this topic have been published [7].

In 2019, Ozdemir et al. [74] proposed their own modification of the Kostuik transiliac fixation using connectors of a special shape for connecting the transverse rod to the main structure. After analyzing the treatment outcomes of 21 patients with neuromuscular deformities, the authors point out the high efficiency of the proposed technique and the possibility of using it as an alternative to other modern methods of lumbopelvic fixation. We believe that this technique, due to the relative simplicity and safety of implementation, deserves consideration and analysis of long-term results for a more accurate evaluation.

In a certain sense, the idea of transabdominal fixation is reflected in the so-called T-Constructs (Fig. 10), the successful use of which is characterized in the treatment of neuromuscular scoliosis. The transversely positioned rod was fixed to the screws in the S1 vertebra and with a screw inserted into the iliac bones [75, 76].

Conclusions

The spinopelvic fixation is one of the most urgent problems of spine surgery. The anatomical and biomechanical studies performed, the analysis of errors and complications result in the improvement of techniques. The main indications for spinopelvic fixation have been determined. Nevertheless, the high operational activity in the treatment

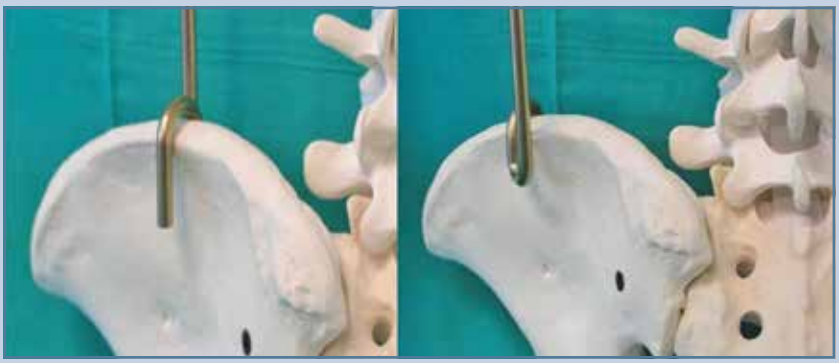

Fig. 9
A positioning option for the S-shaped hook in Dunn – McCarthy spinopelvic fixation [64]

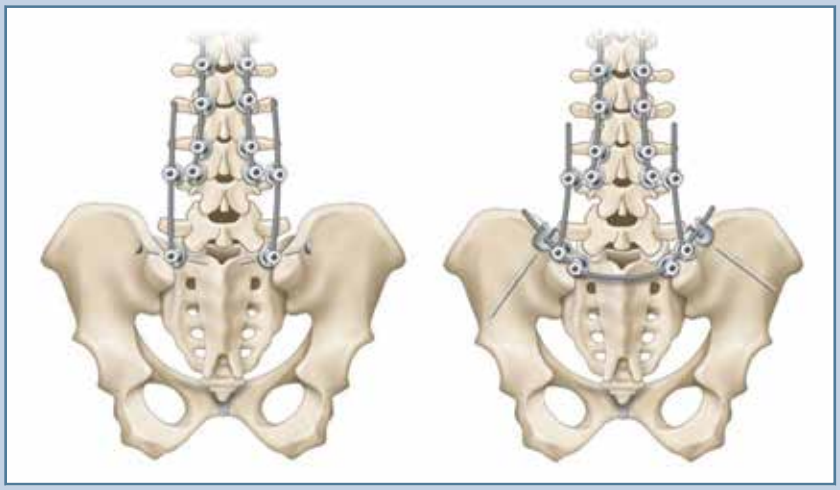

Fig. 10
Variants of spinopelvic fixation using a T-Construct [60]

of spinal pathology, the widespread introduction of corrective operations, osteotomies identify new indications and cause the emergence of new issues for surgeons. The historical evaluation of the development of methods of spinopelvic fixation is essential for the further evolution of surgical techniques and instrumentation. Something, of course, remained only as a history. Some techniques are being improved and applied nowadays. Nevertheless, it is indisputable that this knowledge provides a significant foundation for further development.

A literature review of the current standard of spinopelvic fixation via iliac screws, as well as the performance of fixation in non-standard situations and an analysis of the role of anterior fusion will be described in the second part of the article.

The study had no sponsors. The authors declare that they have no conflict of interest.

References

1. **Kornblatt MD, Casey MP, Jacobs RR.** Internal fixation in lumbosacral spine fusion. A biomechanical and clinical study. Clin Orthop Relat Res. 1986;(203):141–150.
2. **Asher MA, StrippgenWE.** Anthropometric studies of the human sacrum relating to dorsal transsacral implant designs. Clin Orthop Relat Res.1986;(203):58–62.
3. **Mirkovic S, Abitbol JJ, Steinman J, Edwards CC, Schaffler M, Massie J, Garfin SR.** Anatomic consideration for sacral screw placement. Spine 1991;16(6 Suppl):S289–S294.
4. **McCord DH, Cunningham BW, Shono Y, Myers JJ, McAfee PC.** Biomechanical analysis of lumbosacral fixation. Spine. 1992;17(8 Suppl):235–243. DOI: 10.1097/00007632-199208001-00004.
5. **O'Brien MF.** Sacropelvic fixation in spinal deformity. In: Arlet V, Carl AL, O'Brien MF, DeWald RL, eds. Spinal Deformities: The Comprehensive Text. New York, 2003:601–614.
6. **Kebaish K, El Dafrawy MH.** Sacropelvic fixation. In: Operative Techniques: Spine Surgery. Elsevier, 2017:290–302. DOI: 10.1016/B978-0-40066-4.00032-1.
7. **Esmende SM, Shah KN, Daniels AH.** Spinopelvic fixation. J Am Acad Orthop Surg. 2018;26:396–401. DOI: 10.5435/jaaos-d-15-00738.
8. **Moshirfar A, Rand FF, Sponseller PD, Parazin J, Khanna AJ, Kebaish KM, Stinson JT, Riley LH 3rd.** Pelvic fixation in spine surgery. Historical overview, indications, biomechanical relevance, and current techniques. J Bone Joint Surg Am. 2005;87 Suppl 2:89–106. DOI: 10.2106/JBJS.E.00453.
9. **Santos ERG, Rosner MK, Perra JH, Polly DW Jr.** Spinopelvic fixation in deformity: a review. Neurosurg Clin N Am. 2007;18:373–384. DOI: 10.1016/j.nec.2007.02.009.
10. **El Dafrawy MH, Raad M, Okafor L, Kebaish KM.** Sacropelvic fixation: a comprehensive review. Spine Deform. 2019;7:509–516. DOI: 10.1016/j.jspd.2018.11.009.
11. **Lombardi JM, Shillingford JN, Lenke LG, Lehman RA.** Sacropelvic fixation: when, why, how? Neurosurg Clin N Am. 2018;29:389–397. DOI: 10.1016/j.nec.2018.02.001.
12. **Kebaish KM.** Sacropelvic fixation: techniques and complications. Spine. 2010;35: 2245–2251. DOI: 10.1097/brs.0b013e3181f5cfae.
13. **Cunningham BW, Sefter JC, Hu N, Kim SW, Bridwell KH, McAfee PC.** Biomechanical comparison of iliac screws versus interbody femoral ring allograft on lumbosacral kinematics and sacral screw strain. Spine. 2010;35:E198–E205. DOI: 10.1097/BRS.0b013t3181c142bf.
14. **Kostuik JP.** Treatment of scoliosis in the adult thoracolumbar spine with special reference to fusion to the sacrum. Orthop Clin North Am. 1988;19:371–381. DOI: 10.1016/S0030-5898(20)303117-5.
15. **Kostuik JP, Errico TJ, Gleason TF.** Techniques of internal xation for degenerative conditions of the lumbar spine. Clin Orthop Relat Res. 1986;(203):219–231.
16. **Perra JH.** Techniques of instrumentation in long fusions to the sacrum. Orthop Clin North Am. 1994;25:287–299. DOI: 10.1016/S0030-5898(2)31910-6.
17. **Kim YJ, Bridwell KH, Lenke LG, Cheh G, Baldus C.** Results of lumbar pedicle subtraction osteotomies for xed sagittal imbalance: a minimum 5-year follow-up study. Spine. 2007;32:2189–2197. DOI: 10.1097/BRS.0b013e31814b8371.
18. **Suk SI, Chung ER, Kim JH, Kim SS, Lee JS, Choi WK.** Posterior vertebral column resection for severe rigid scoliosis. Spine. 2005;30:1682–1687. DOI: 10.1097/01.brs.0000170590.21071.c1.
19. **Suk SI, Chung ER, Lee SM, Lee JH, Kim SS, Kim JH.** Posterior vertebral column resection in xed lumbosacral deformity. Spine. 2005;30:E703–E710. DOI: 10.1097/01.brs.0000188190.90034.be.
20. **Hu SS, Bradford DS, Transfeldt EE, Cohen M.** Reduction of high-grade spondylolisthesis using Edwards instrumentation. Spine. 1996;21:367–371. DOI: 10.1097/00007632-199602010-00023.
21. **Boos N, Marchesi D, Zuber K, Aebi M.** Treatment of severe spondylolisthesis by reduction and pedicular xation. A 4-6-year follow-up study. Spine. 1993;18:1655–1661. DOI: 10.1097/00007632-199309000-00014.
22. **Cunningham BW, Lewis SJ, Long J, Dmitriev AE, Linville DA, Bridwell KH.** Biomechanical evaluation of lumbosacral reconstruction techniques for spondylolisthesis: an in vitro porcine model. Spine. 2002;27:2321–2327. DOI: 10.1097/00007632-200211010-00004.
23. **Molinari RW, Bridwell KH, Lenke LG, Ungasta FF, Riew KD.** Complications in the surgical treatment of pediatric high-grade, isthmic dysplastic spondylolisthesis. A comparison of three surgical approaches. Spine. 1999;24:1701–1711. DOI: 10.1097/00007632-199908150-00012.
24. **Shuf ebarger HL, Geck MJ.** High-grade isthmic dysplastic spondylolisthesis: monosegmental surgical treatment. Spine. 2005;30(6 Suppl):S42–S48. DOI: 10.1097/01.brs.0000155583.55856.f9.
25. **Benson ER, Thomson JD, Smith BG, Banta JV.** Results and morbidity in a consecutive series of patients undergoing spinal fusion for neuromuscular scoliosis. Spine. 1998;23:2308–2317. DOI: 10.1097/00007632-199811010-00012.
26. **Myung KS, Lee C, Skaggs DL.** Early pelvic xation failure in neuromuscular scoliosis. J Pediatr Orthop. 2015;35:258–265. DOI: 10.1097/BPO.0000000000000254.
27. **Gau YL, Lonstein JE, Winter RB, Koop S, Denis F.** Luque-Galveston procedure for correction and stabilization of neuromuscular scoliosis and pelvic obliquity: a review of 68 patients. J Spinal Disord. 1991;4:399–410. DOI: 10.1097/00002517-199112000-00001.
28. **Jones CB, Sietsema DL, Hoffmann MF.** Can lumbopelvic xation salvage unstable complex sacral fractures? Clin Orthop Relat Res. 2012;470:2132–2141. DOI: 10.1007/s11999-012-2273-z.
29. **Keel MJ, Benneker LM, Siebenrock KA, Bastian JD.** Less invasive lumbopelvic stabilization of posterior pelvic ring instability: technique and preliminary results. J Trauma. 2011;71:E62–E70. DOI: 10.1097/TA.0b013e3182092e66.
30. **Schildhauer TA, Bellabarba C, Nork SE, Barei DP, Routt ML Jr, Chapman JR.** Decompression and lumbopelvic xation for sacral fracture-dislocations with spino-pelvic dissociation. J Orthop Trauma. 2006;20:447–457. DOI: 10.1097/00005131-200608000-00001.
31. **Balderston RA, Winter RB, Moe JH, Bradford DS, Lonstein JE.** Fusion to the sacrum for nonparalytic scoliosis in the adult. Spine. 1986;11:824–829. DOI: 10.1097/00007632-198610000-00017.
32. **Harrington PR.** Treatment of scoliosis. Correction and internal fixation by spine instrumentation. J Bone Joint Surg Am. 1962;44:591–610.
33. **Ogilvie JW, Schendel M.** Comparison of lumbosacral fixation devices. Clin Orthop Relat Res. 1986;(203):120–125.
34. **Kazmin AI, Kon IS, Belenky VE.** Scoliosis. Moscow, 1981. In Russian.
35. **Zatsepin ST.** Bone Pathology of Adults. Moscow, 2001. In Russian.
36. **Luque ER.** Segmental spinal instrumentation for correction of scoliosis. Clin Orthop Relat Res. 1982;(163):192–198.
37. **Luque ER.** The anatomic basis and development of segmental spinal instrumentation. Spine. 1982;7:256–259. DOI: 10.1097/00007632-198205000-00010.
38. **Luque ER.** Interpeduncular segmental fixation. Clin Orthop Relat Res. 1986;(203):54–57.
39. **King AG, Thomas KA, Eiserloh HL 3rd, Mills TE, Pisciotta DN.** Analysis of the STIF technique for spino-pelvic fixation: clinical results in 19 patients with neuromuscular scoliosis. J Pediatr Orthop. 2000;20:667–676. DOI: 10.1097/00004694-200009000-00023.
40. **Devlin VJ, Boachie-Adjei O, Bradford DS, Ogilvie JW, Transfeldt EE.** Treatment of adult spinal deformity with fusion to the sacrum using CD instrumentation. J Spinal Disord. 1991;4:1–14.

41. **Allen BL Jr, Ferguson RL.** The Galveston technique of pelvic fixation with L-rod instrumentation of the spine. Spine. 1984;9:388–394. DOI: 10.1097/00007632-198405000-00011.
42. **Boachie-Adjei O, Lonstein JE, Winter RB, Koop S, vanden Brink K, Denis F.** Management of neuromuscular spinal deformities with Luque segmental instrumentation. J Bone Joint Surg Am. 1989;71:548–562.
43. **Kostuik JP, Hall BB.** Spinal fusions to the sacrum in adults with scoliosis. Spine. 1983;8:489–500. DOI: 10.1097/00007632-198307000-00006.
44. **Allen BL Jr, Ferguson RL.** The Galveston technique for the L-rod instrumentation of the scoliotic spine. Spine. 1982;7:276–284. DOI: 10.1097/00007632-198205000-00014.
45. **Dayer R, Ouellet JA, Saran N.** Pelvic fixation for neuromuscular scoliosis deformity correction. Curr Rev Musculoskelet Med. 2012;5:91–101. DOI: 10.1007/s12178-012-9122-2.
46. **Allen BL Jr, Ferguson RL.** The Galveston experience with L-rod instrumentation for adolescent idiopathic scoliosis. Clin Orthop Relat Res. 1988;(229):59–69.
47. **Broom MJ, Banta JV, Renshaw TS.** Spinal fusion augmented by Luque-rod segmental instrumentation for neuromuscular scoliosis. J Bone Joint Surg Am. 1989;71:32–44.
48. **Saer EH 3rd, Winter RB, Lonstein JE.** Long scoliosis fusion to the sacrum in adults with nonparalytic scoliosis. An improved method. Spine. 1990;15:650–653. DOI: 10.1097/00007632-199007000-00007.
49. **Emami A, Deviren V, Berven S, Smith JA, Hu SS, Bradford DS.** Outcome and complications of long fusions to the sacrum in adult spine deformity: Luque – Galveston, combined iliac and sacral screws, and sacral fixation. Spine. 2002;27:776–786. DOI: 10.1097/00007632-200204010-00017.
50. **Cotrel Y, Dubousset J.** New segmental posterior instrumentation of the spine. Orthop Trans. 1985;9:118.
51. **Cotrel Y, Dubousset J, Guillaumat M.** New universal instrumentation in spinal surgery. Clin Orthop Relat Res. 1988;227:10–23.
52. **Camp JF, Caudle R, Ashmun RD, Roach J.** Immediate complications of Cotrel Dubousset instrumentation to the sacro-pelvis. A clinical and biomechanical study. Spine. 1990;15:932–941. DOI: 10.1097/00007632-199009000-00018.
53. **Stovall DO Jr, Goodrich JA, Lundy D, Standard SC, Joe C, Preston CD.** Sacral fixation technique in lumbosacral fusion. Spine. 1997;22:32–37. DOI: 10.1097/00007632-199701010-00006.
54. **Jackson RP, McManus AC.** The iliac buttress. A computed tomography study of sacral anatomy. Spine. 1993;18:1318–1328.
55. **Glazer PA, Colliou O, Lotz JC, Bradford DS.** Biomechanical analysis of lumbosacral fixation. Spine. 1996;21:1211–1222. DOI: 10.1097/00007632-199605150-00015.
56. **Lebwohl NH, Cunningham BW, Dmitriev A, Shimamoto N, Gooch L, Devlin V, Boachie-Adjei O, Wagner TA.** Biomechanical comparison of lumbosacral fixation techniques in a calf spine model. Spine. 2002;27:2312–2320. DOI: 10.1097/00007632-200211010-00003.
57. **Ilharreborde B, Hoffmann E, Tavakoli S, Queinnec S, Fitoussi F, Presedo A, Pennecot GF, Mazda K.** Intrasacral rod fixation for pediatric long spinal fusion: results of a prospective study with a minimum 5-year follow-up. J Pediatr Orthop. 2009;29:594–601. DOI: 10.1097/BPO.0b013e3181b2b403.
58. **Fukuda K, Takemitsu M, Machida M, Asazuma T.** Lumbosacral fixation using sacroiliac buttress screws: a modification to the Jackson technique with intrasacral rods. Scoliosis. 2014;9:8. DOI: 10.1186/1748-7161-9-8.
59. **McCarthy RE, Dunn H, McCullough FL.** Luque fixation to the sacral ala using the Dunn-McCarthy modification. Spine. 1989;14:281–283. DOI: 10.1097/00007632-198903000-00007.
60. **Bachy M, Kabbaj R, Bouyer B, Mary P, Vialle R.** Extensiones a la pelvis de las osteosintesis raquideas. EMC – T cnicas Quir rgicas – Ortopedia y Traumatologia. 2014;6:1–16. DOI: 10.1016/S2211-033X(14)67572-1.
61. **Kolesov SV, Kushel YuV, Sivacheva OS.** Surgical treatment of patients with caudal regression syndrome. Hir. Pozvonoc. 2016;13(2):28–35. In Russian. DOI: 10.14531/ss2016.2.28-35.
62. **Mikhaylovskiy MV, Suzdalov VA, Dolotin DN, Sadovaya TN.** Results of multistage surgical treatment of scoliosis in the first decade of life using VEPTR instrumentation. Hir. Pozvonoc. 2017;14(3):8–14. In Russian. DOI: 10.14531/ss2017.3.8-14.
63. **Walick KS, King JT, Johnston CE, Rathjen KE.** Neuropathic lower extremity pain following Dunn-McCarthy instrumentation. Spine. 2008;33:E877–E880. DOI: 10.1097/brs.0b013e3181877b99.
64. **Ramirez N, Flynn JM, Smith JT, Vitale M, Sturm PF, D Amato C, Samdani A, Machiavelli R, El-Hawary R.** Use of the S-hook for pelvic fixation in rib-based treatment of early-onset scoliosis: a multicenter study. Spine. 2015;40:816–822. DOI: 10.1097/brs.0000000000000443.
65. **Warner WC Jr, Fackler CD.** Comparison of two instrumentation techniques in treatment of lumbar kyphosis in myelodysplasia. J Pediatr Orthop. 1993;13:704–708. DOI: 10.1097/01241398-199311000-00002.
66. **Odent T, Arlet V, Ouellet J, Bitan F.** Kyphectomy in myelomeningocele with a modified Dunn-McCarthy technique followed by an anterior inlayed strut graft. Eur Spine J. 2004;13:206–212. DOI: 10.1007/s00586-003-0662-4.
67. **Leong JC, Lu WW, Zheng Y, Zhu Q, Zhong S.** Comparison of the strengths of lumbosacral fixation achieved with techniques using one and two triangulated sacral screws. Spine. 1998;23:2289–2294. DOI: 10.1097/00007632-199811010-00008.
68. **Early S, Mahar A, Oka R, Newton P.** Biomechanical comparison of lumbosacral fixation using Luque-Galveston and Colorado II sacropelvic fixation: advantage of using locked proximal fixation. Spine. 2005;30:1396–1401. DOI: 10.1097/01.brs.0000166530.87923.5b.
69. **Zindrick MR, Wiltse LL, Widell EH, Thomas JC, Holland WR, Field BT, Spencer CW.** A biomechanical study of intrapeduncular screw fixation in the lumbosacral spine. Clin Orthop Relat Res. 1986;(203):99–112.
70. **Park YS, Kim HS, Baek SW, LeeSH.** Lumbosacral fixation using the diagonal S2 screw for long fusion in degenerative lumbar deformity: technical note involving 13 cases. Clin Orthop Surg. 2013;5:225–229. DOI: 10.4055/cios.2013.5.3.225.
71. **Widmann RF, Hresko MT, Hall JE.** Lumbosacral fusion in children and adolescents using the modified sacral bar technique. Clin Orthop Relat Res. 1999;(364):85–91. DOI: 10.1097/00003086-199907000-00012.
72. **Kostuik JP, Musha Y.** Extension to the sacrum of previous adolescent scoliosis fusions in adult life. Clin Orthop Relat Res.1999;(364):53–60. DOI: 10.1097/00003086-199907000-00008.
73. **Kostuik JP.** Spinopelvic fixation. Neurol India. 2005;53:483–488. DOI: 10.4103/0028-3886.22618.
74. **Ozdemir HM, Demirkale I, Ozdemir M, Aksekili MAE**. The modified Kostuik transilial bar technique has acceptable results in neuromuscular spinal deformity correction. J Pediatr Orthop B. 2019;28:385–392. DOI: 10.1097/bpb.0000000000000626.
75. **Zahi R, Thevenin-Lemoine C, Rogier A, Constantinou B, Mary P, Vialle R.** The "T-construct" for spinopelvic fixation in neuromuscular spinal deformities. Preliminary results of a prospective series of 15 patients. Childs Nerv Syst. 2011;27:1931–1935. DOI: 10.1007/s00381-011-1411-3.
76. **Bouyer B, Bachy M, Zahi R, Thevenin-Lemoine C, Mary P, Vialle R.** Correction of pelvic obliquity in neuromuscular spinal deformities using the "T construct": results and complications in a prospective series of 60 patients. Eur Spine J. 2013;23:163–171. DOI: 10.1007/s00586-013-2847-9.

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