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MIDLINE LUMBAR INTERBODY FUSION IN THE TREATMENT OF DEGENERATIVE SPONDYLOLISTHESIS. COMPARATIVE STUDY OF CLINICAL EFFICACY

321.21 NEUROSURGERY

Summary of the Ph.D. Thesis in Medical Sciences

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INTRODUCTION

Relevance of the issue under research

Degenerative spondylolisthesis (DSPL) is one of the most common degenerative lesions of the lumbar spine, affecting up to 14% of the population. Although there is no consensus on the optimal surgical treatment, currently the standard technique of treating patients with DSPL includes decompression of nervous structures and stabilization of the spine via one of the traditional methods of intersomatic arthrodesis (PLIF, TLIF, PLF). While being very effective in achieving intervertebral fusion, the traditional technique is associated with important drawbacks, such as the significant muscle dissection required for the insertion of pedicle screws. The traditional technique is also associated with increased surgical morbidity due to iatrogenic muscle and soft tissue injury. Long skin incisions, injury of medial branch of the spinal dorsal ramus and prolonged soft tissue retraction can cause denervation and ischemic necrosis of paravertebral muscles. Loss of functional muscle support may subsequently lead to segmental instability, increased biomechanical stress and persistence of low back pain.

To address some of these shortcomings, the Midline Lumbar Interbody Fusion (MIDLIF®) technique has recently been developed. This technique provides an acceptable success rate of intervertebral fusion while making use of the minimally invasive features of the cortical bone trajectory (CBT) pedicle screw fixation of the spine. The trajectory through the cortical bone of the pars interarticularis was proposed by Santoni et al. in 2009 as an alternative method of pedicle screw implantation in patients with vertebral osteoporosis. Biomechanical tests conducted by Santoni demonstrated that CBT screws have higher pullout resistance than conventional transpedicular screws.

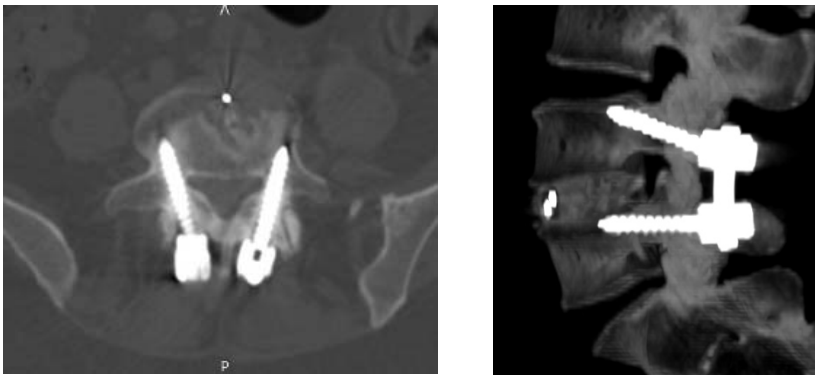

Fig. 1. MIDLIF with CBT pedicle screws

Due to the more medial insertion point and the divergent angulation of the CBT screws, following theoretical benefits of the MIDLIF technique over traditional arthrodesis procedures have been hypothesized:

- Limited muscle dissection and retraction could reduce bleeding, decrease local pain and accelerate postoperative functional rehabilitation.
- Avoiding injury to the medial branches of the spinal dorsal ramus could help reduce postoperative radicular pain.
- Absence of contact between screw head and the inferior articular process could decrease the risk of adjacent segment disease.
- The divergent trajectory of CBT screws could decrease the risk of iatrogenic injury to major abdominal vessels.

The first report on the clinical use of CBT screws for midline interbody fusion (MIDLF) dates back to 2014 [14]. Since then, multiple preclinical (biomechanical, morphometric,

anatomical, radiological) and clinical studies have been published. These studies have attempted to demonstrate the superiority or non-inferiority of CBT screws over traditional pedicle screws. Unfortunately, most of these studies were retrospective, non-randomized, with small sample and non-representative populations. To date, there are no prospective, randomized, controlled clinical trials that would evaluate the efficacy of the MIDLIF technique applied **exclusively** in the treatment of degenerative lumbar spondylolisthesis. Based on these arguments, it became necessary to conduct a study with a high level of scientific evidence, to assess the reliability of the relatively new CBT pedicle screw fixation technique.

The aim of the scientific experiment was to study the clinical efficacy and technical features of Midline Lumbar Interbody Arthrodesis (MIDLIF) with neuronavigation-guided cortical bone trajectory pedicle screws, in order to optimize the surgical treatment algorithm for patients with degenerative spondylolisthesis.

The research **objectives** included:

1. Assessment of the intervertebral fusion success rate of the MIDLIF technique compared to traditional arthrodesis procedures (PLIF / TLIF).
2. To evaluate the effectiveness of the MIDLIF technique in improving the pain (lumbar, radicular), the functional disability and the quality of life of patients with DSPL.
3. Comparative analysis (MIDLIF vs. traditional techniques) of the parameters associated with peri-operative surgical morbidity, in order to quantify the invasiveness of the studied techniques.
4. To study the technical features, advantages and difficulties of using spinal neuronavigation in MIDLIF arthrodesis. Establish an optimal intraoperative setup of the neuronavigation system for the cortical bone trajectory guidance.
5. Development of an optimized algorithm for evaluation and surgical treatment of patients with degenerative lumbar spondylolisthesis.

The scientific research project was approved by the Research Ethics Committee of "Nicolae Testemitanu" State University of Medicine and Pharmacy (verbal process no. 44 of 12.12.2016).

Research Materials and Methods

In the period 2016 - 2022 at the Department of Neurosurgery of the Republican Clinical Hospital "Timofei Mosneaga", an experimental scientific study was conducted according to the model of randomized controlled trials, analysing the clinical and radiological outcomes of the MIDLIF arthrodesis procedure, used in the treatment of patients with degenerative lumbar spondylolisthesis, and comparing them with the results of traditional lumbar interbody fusion techniques (TLIF / PLIF). The research was conducted on a sample of 112 patients, randomly assigned to one of the study groups. The control group included patients with traditional interbody fusions and the research group – patients to whom the MIDLIF technique was applied.

The study addressed an important scientific problem, which was the scientific foundation of MIDLIF technique capacity to provide a mechanical stability and a fusion success rate similar to traditional arthrodesis procedures, while offering the advantages of reduced surgical morbidity specific for minimally invasive techniques, thus promoting the MIDLIF arthrodesis as a safe and effective surgical alternative for the treatment of degenerative spondylolisthesis.

Theoretical significance and applied significance of the research. The study determined the optimal intraoperative setup of the spinal neuronavigation for MIDLIF arthrodesis by adjusting the reference array fixation procedure. The causes of specific complications for MIDLIF

arthrodesis (pars or pedicle fracture) were identified, and the surgical technique was optimized in order to minimize the risk of their occurrence. Based on the results of the study, an optimized algorithm for evaluation and surgical treatment of patients with degenerative spondylolisthesis was developed, scientifically validated and implemented as institutional protocol at the Timofei Mosneaga Republican Clinical Hospital. This algorithm, as well as the new MIDLIF arthrodesis technique can be applied in the practice of most clinics specialized in neurosurgery and spinal orthopaedics in our country.

The scientific research resulted in the implementation in the practice of the Neurosurgery Clinic of the Republican Clinical Hospital of the following techniques and procedures:

- Introduction of the MIDLIF arthrodesis technique in the treatment of degenerative spinal instability.
- Implementation of intraoperative image guidance of traditional and cortical bone trajectory pedicle screw insertion using spinal neuronavigation (BrainLab). An optimal setup of the neuronavigation for guiding the CBT trajectory was established by adjusting the dynamic reference array fixation procedure.
- Introduction of intraoperative neurophysiological monitoring for pedicle screw insertion guidance (traditional and CBT pedicle screws).
- Implementation of the unilateral laminectomy for bilateral spinal canal decompression, through a minimally invasive " Over the Top " approach as an alternative treatment for degenerative spondylolisthesis.
- Introduction of bone quality assessment methods using DEXA scan densitometry, supplemented by the measurement of bone density in Hounsfield units using conventional computed tomography.
- Introduction of a method to assess segmental instability by measuring translational motion of the vertebrae on orthostatic spinal radiographs versus the MRI or CT images taken in the horizontal position of the patient, as an alternative to dynamic spinal radiography.
- Implementation of intervertebral fusion assessment using computed tomography, based on the Williams protocol and the Brantigan-Steffee-Fraser classification.
- Implementation of the Institutional Clinical Protocol for diagnosis and treatment of patients with DSPL in "Timofei Moșneaga" Republican Clinical Hospital.

The results of the scientific study have been reflected in numerous publications in specialized journals, in the materials of national and international scientific conferences and have been presented at various scientific communication sessions in the Republic of Moldova, Austria, Turkey, Romania, Ukraine and Russia, including the XVI World Congress of Neurosurgery, WFNS 2017, and European EANS2023 Barcelona Congress.

Keywords: degenerative lumbar spondylolisthesis, midline lumbar interbody fusion, transpedicular screw fixation, cortical bone trajectory pedicle screw, spinal neuronavigation.

SUMMARY OF CHAPTERS

CHAPTER 1 includes an in-depth analysis of existing scientific material related to the subject of the thesis.

The cortical bone trajectory (CBT) was originally designed to improve the mechanical efficiency of pedicle screws in patients with osteoporosis. Santoni and colleagues (2009) demonstrated that anchoring the CBT pedicle screw in higher density bone resulted in a 30% increase in its pull-out strength and a rigidity equivalent to that of traditional pedicle screws [20]. Matsukawa et al. demonstrated a 1.7-fold higher insertion torque for transcortical screws and superior strength of CBT constructs in flexion and extension fatigue testing [11-13]. Other authors reconfirmed a biomechanical efficiency similar to traditional pedicle screws (TPd) when using shorter and smaller diameter CBT screws [15]. Li et al (2018) found that CBT screws were superior to traditional pedicle screws in terms of insertion torque, pull-out strength, toggle resistance and force required to loosen the screw in osteoporotic bone tissue [9].

To date, there is only one prospective randomised study comparing the clinical efficacy of CBT versus TPd screws. Lee et al (2015) found significantly lower values for intraoperative bleeding (360 vs 450 ml, $p = 0.04$), operative time (2.1 vs 2.6 h, $p = 0.03$) and incision length (73 vs 107 mm, $p = 0.03$) in the CBT group [7]. Subsequently, other comparative studies have demonstrated a significant reduction of surgical morbidity (blood loss, length of incision, length of operation, length of hospital stay) for CBT [2, 10, 19, 22].

The application of cortical bone trajectory screws appears to have clinical and radiological outcomes similar to TPd screws, both in the short and long term. Lee et al (2018) demonstrated a similar fusion rate for CBT and TPd screws ($p > 0.99$) two years post-operatively. Compared to traditional pedicle fixation, the visual analogue scale (VAS) for low back pain was significantly lower only one week after surgery in patients who underwent CBT fixation, while leg pain, Oswestry Disability Index (ODI) and quality of life (SF-12) were similar at all stages of clinical monitoring. Perioperative complications, including loosening of the screws, wound infection and recurrence of radicular pain, were similar in both groups [8].

Multiple meta-analyses have demonstrated a shorter incision length, shorter hospital stay and lower intraoperative bleeding for CBT [4, 23]. High-quality studies also concluded that CBT and TPd screws were similar in terms of fusion rates, reoperations, perioperative complications and VAS scores for lumbar and radicular pain, while one study demonstrated a better ODI score and a lower incidence of adjacent segment disease with the application of CBT screws [23].

Although the cortical bone trajectory certainly has theoretical advantages, a careful review of the literature reveals clear limitations in current knowledge of the biomechanical characteristics and clinical outcomes associated with the application of transcortical screws [5].

For instance, Perez-Orribo et al (2013) found that CBT screws are significantly less stiff than traditional pedicle screws in lateral bending and rotation, leading to the occurrence of micro-mobility and a decrease in their mechanical efficiency [16]. Several authors have invoked this logic to explain the lower success rate of fusion and the poorer early clinical results they observed with CBT screw fixation [3, 18]. Based on several biomechanical studies, CBT screws are considered equivalent to TPd screws in terms of stability only when combined with an interbody device (cage).

A recent systematic review found conflicting differences in postoperative pain, operation time and complication rates. Only the volume of blood loss was in favour of CBT [17]. The

current literature is full of conflicting evidence and low-quality studies, which discourages many surgeons from applying the new CBT screw fixation technique in clinical practice.

CHAPTER 2 includes the research materials and methods.

In order to achieve the outlined objectives, a scientific analytical study was carried out following the model of prospective randomized controlled clinical trials, comparing 2 groups:

Research group L_1 included patients treated surgically by the experimental Midline Lumbar Interbody Fusion (MIDLIF) technique.

Control group L_0 included patients treated surgically by the traditional method of Posterior Lumbar Interbody Fusion (PLIF) or Transforaminal Interbody Fusion (TLIF).

The size of the research sample was estimated by applying the following formula:

$$n = \frac{1}{(1-f)} \times \frac{2(Z_\alpha + Z_\beta)^2 P(1-P)}{(P_o - P_1)^2}$$

where:

P_o = Proportion of patients in whom intervertebral fusion was achieved by the traditional method. The success rate of achieving an image proven fusion in patients with spondylolisthesis using the traditional arthrodesis technique, according to the literature [1, 21], is 75.0% on average (P_0=0,75).

P_1 = Proportion of patients with successful interbody fusion in the research group. We assume that the success of treatment after application of the new surgical technique will increase to 95.0% (P1 = 0.95).

$P = (P_0 + P_1)/2$=0,85

Zα – table value. When the significance threshold of „**α”** is 5%, the coefficient Zα =1.96

Z_β – table value. When „***β”*** – the statistical power of comparison is 80,0%, the coefficient Z_β = 0,84

f = Proportion of subjects expecting to drop out from the study for various reasons q = 1/(1-f), f=10,0% (0,1)

Research batch ratio is 1:1

By entering the data into the formula, we obtain:

$$n = \frac{1}{(1-0.1)} \times \frac{2(1.96+0.84)^2 x 0.85 x 0.15}{(0.75-0.95)^2} = 56$$

Consequently, two research groups were created: the L_1 research group, comprising a minimum of 56 patients with degenerative spondylolisthesis to whom the experimental surgical technique was applied, and the L_0 control group, comprising at least 56 patients with degenerative spondylolisthesis to whom the conventional surgical technique was applied.

The primary endpoint of treatment efficacy, compared between groups, was successful intervertebral fusion at 1 year post-operatively.

The study **inclusion criteria** were as follows:

- Presence of indications for surgical treatment via one level arthrodesis for degenerative spondylolisthesis with foraminal stenosis, degenerative disc disease and degenerative spinal instability.
- Low grade spondylolisthesis (grade I-II)
- Age: 18 years and older
- Patient is competent to give informed consent
- Acceptance to participate in research.

- **The exclusion criteria for the study were:**
- High grade spondylolisthesis (Meyerding gr. III-V)
- Need for interbody fusion at 3 or more vertebral levels
- Spinal canal stenosis of non-degenerative origin: tumour, trauma
- Previous lumbar interbody fusion surgery
- Active systemic or local infection
- Permanent neurological deficit, unrelated to the lumbar spine pathology
- History of alcohol or drug abuse
- Severe vertebral osteoporosis
- Presence of contraindications to surgical treatment: severe medical comorbidities, immunosuppressive therapy.
- Lack of a permanent residence address in the Republic of Moldova, emigrants
- Pregnant women or women planning pregnancy for the next 1-2 years
- Patient unable to complete questionnaire: dementia, intellectual retardation
- Patient unable to provide voluntary consent
- Patient refusal to participate in research.

Study design

Patients with degenerative spondylolisthesis recruited for surgical treatment first undergo a complex clinical and radiological examination. The clinical examination included a thorough history of the disease and basic demographic data collection, as well as a detailed neurological examination. Emphasis was placed on identifying risk factors for the development of postoperative spinal pseudarthrosis, such as the patient's age and sex, vicious habits (smoking, chronic alcohol abuse), chronic use of glucocorticoids and NSAIDs, diabetes mellitus, viral hepatitis and previous spinal surgery.

In addition, the patient received pre-operative self-assessment questionnaires for the Visual Analogue Scale (VAS) for the intensity of low back pain and radiating radicular pain, the Oswestry Disability Index (ODI) and 12-Item Short Form Survey (SF-12).

Preoperative radiological examination must include magnetic resonance imaging (MRI), bone window CT, orthostatic spine radiography and/or functional spine radiography. All patients also underwent DEXA bone densitometry of the lumbar spine and femoral neck to assess the quality of vertebral bone tissue and rule out the presence of osteoporosis.

Study inclusion and exclusion criteria are then applied. If the patient meets one of the exclusion criteria, he or she is not included in the study and, in this case, the standard treatment for the condition is applied (traditional arthrodesis or bone decompression without instrumentation). If all the inclusion criteria and none of the exclusion criteria are met, the

patient is offered participation in the randomised clinical trial and asked to give informed consent. If, for any reason, the patient refuses to take part in the study, he or she is excluded from the research, and treated by one of the standard surgical methods.

Patients included in the clinical trial were randomised by the „sealed envelope" method and randomly assigned to one of two study groups: the L_0 control group, which included patients treated with traditional interbody fusion techniques (TLIF or PLIF) and the L_1 research group, which included patients to whom the MIDLIF arthrodesis technique with CBT screws was applied. Each study group comprised 56 patients, with a 1:1 ratio between groups.

Patients were assessed clinically and radiologically at 6 weeks, 3 months, 6 months and 1 year after surgery. Clinical assessment included a thorough neurological examination and VAS, ODI and SF-12 self-report questionnaires. Radiological exam included orthostatic radiography of the spine at all stages of clinical monitoring and thin-section (1 mm) bone window computed tomography at one year post-operatively to assess the success of interbody fusion. The Brantigan-Steffee-Fraser classification has been used to describe the success of arthrodesis. According to this classification, there are three types of interbody fusion. Type BSF-1 involves true radiographic pseudarthrosis, indicated by imaging signs of vertebral fixation loosening, such as the appearance of radiolucent areas at the periphery of the interbody cage and around the pedicle screws, significant resorption of the bone graft, dislocation and subsidence of the interbody cages with significant loss of disc height, stress fracture of the screws, and loss of correction of vertebral slip. Type BSF-2, or the "locked pseudarthrosis", is indicated by the presence of a horizontal line of radiolucency across the centre of the bone graft inside interbody cages, and solid bony fusion at the level of both vertebral endplates. Type BSF-3 represents solid radiographic fusion, with the bone graft taking the form of continuous bridging bone tissue connecting the two adjacent vertebral endplates.

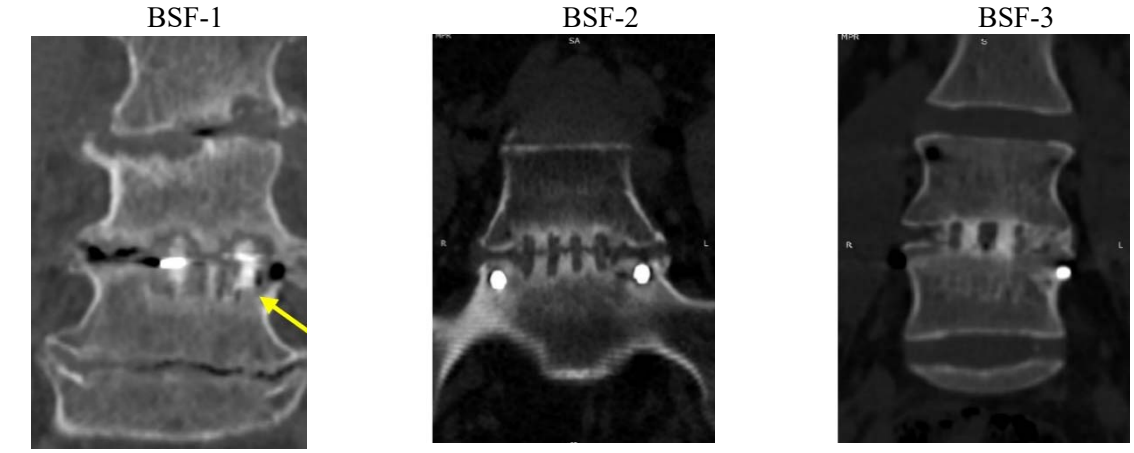

Fig. 2. Types of interbody fusion according to the Brantigan-Steffee-Fraser classification

In addition, intra- and post-operative parameters associated with surgical morbidity, such as length of incision, intra-operative bleeding, need for blood transfusion, duration of operation, surgical muscle tissue damage (postoperative increase in serum CK), exposure to radiation, length of hospital stay and rate of peri-operative complications were recorded prospectively.

Demographic data, success rate of interbody fusion, clinical treatment outcomes derived from self-reported outcomes questionnaires (VAS, ODI, SF-12) and secondary parameters associated with surgical morbidity were transferred to an electronic database created using Microsoft Excel 2003 software. The database was subjected to qualitative and quantitative

statistical analysis using IBM SPSS software version 16.0 (SPSS, Chicago, IL, USA), with the application of descriptive statistical methods (Mean, Median, Standard Deviation, Interquartile Range), Student's t-test (Two-samples independent t-test) for the analysis of continuous variables and Fisher's exact and Pearson Chi-Square (x^2) tests for proportional variables. The statistical significance of the results was assessed for the 95.0% confidence interval ($p < 0.05$). The results of the statistical analysis were represented in the form of tables, graphs and charts.

CHAPTER 3 describes the technical aspects of MIDLIF interbody arthrodesis. The essential operative steps as well as the technical difficulties that initially led to specific complications were outlined. The cause of pars interarticularis and pedicle fracture during insertion of the CoPd screw was found to be insufficient resection of base of the spinous process. Particular attention is paid to the technical aspects of using the spinal neuronavigation system (BrainLab Curve) to guide the CBT screw insertion. The limitations and technical issues associated with the application of neuronavigation in MIDLIF procedure are described and options to overcome these obstacles are proposed. For example, it is pointed out that the neuronavigation setup used to guide the insertion of conventional transpedicular screws is not valid for CBT pedicle screw fixation. Optimal intraoperative setup of the neuronavigation system was proposed, which involves an adjusted procedure of fixing the dynamic reference array to the spinous process of the vertebra located cranially to the fused level, by means of a small additional incision, and the placement of the infrared camera at the patient's head. The reference array is oriented in the cranial direction, placing it in the unobstructed view of the infrared camera. Additionally, the cannulation of the pedicle using the pre-registered tubular drill guide and the electric drill has been suggested to avoid the wobbling of the spine relative to the reference array that typically occurs during manual cannulation of the pedicle, particularly during mechanical impaction of the pedicle probe to penetrate the high-density cortical bone in the pars interarticularis region. Undesirable movement of the vertebrae relative to the reference array can lead to errors in localisation of the neuronavigation-guided surgical instrument. Accidental dislocation of the dynamic frame during manipulations can severely impair navigation accuracy and lead to catastrophic complications.

The use of hockey-stick shaped markers to avoid interference with surgical instruments was also described. Finally, some technical variations of the cortical bone trajectory for caudal screws were described, such as the parallel and the trans-facet trajectories (hybrid CBT fixation technique), as well as the vertebral endplate penetration technique for S1 sacral screws.

CHAPTER 4 is focused on evaluation of the surgical treatment efficacy, by analysing the clinical outcomes of MIDLIF technique and comparing them with the results of traditional interbody fusion techniques, applied in the treatment of degenerative spondylolisthesis patients.

Patients profile

One hundred and twelve (112) patients were randomly assigned to one of the two study groups: the L_0 control group (56 patients) and the L_1 study group (56 patients). Patients in both groups had similar demographic characteristics such as age, sex, smoking status, height, weight, BMI, lumbar pathology and associated systemic diseases ($p>0.05$).

The groups were also homogeneous with regard to the preoperative low back pain and radiating radicular pain intensity (VAS score), the degree of functional disability (ODI score), and the value of physical and mental components of the SF-12 score ($p>0.05$).

Primary outcome measurement. Fusion rate.

Based on three-dimensional thin-slice CT reconstructions, at 1 year postoperatively, 47 patients (83.9%) in the L_0 group and 50 patients (89.3%) in the L_1 group had Brantigan and Steffee (BSF) grade 3 solid interbody fusion. Solid fusion of the bone graft with both vertebral endplates associated with a horizontal zone of radiolucency across the middle of the cage or intervertebral space, known as "locked pseudarthrosis" and corresponding to grade 2 (BSF-2), was observed in 9 patients (16.1%) in group L_0 and 6 patients (10.7%) in group L_1. No cases of true radiological pseudarthrosis (BSF-1) were confirmed in either study group (table 1).
The difference in the rate of interbody fusion between groups was not statistically significant, the p-value being well above 0.05 for both Pearson's Chi-square test (p = 0.405) and Fisher's exact test (p = 0.580).

Table 1: Success rate of interbody fusion

Type of fusion	**Group L_0**		**Group L_1**		**x^2, gl = 1, p**	**Fisher exact**
Pseudarthrosis BSF-1	0	0	0	0	$p = 0.405$	$p = 0.580$
Locked pseudarthrosis BSF-2	16.1%	9	10.7%	6		
Solid fusion BSF-3	83.9%	47	89.3%	50		

Secondary clinical outcome measurement

The VAS score for low back pain 1 year after surgery was significantly lower than the preoperative level in both groups, with the mean score falling from 7.18 ± 2.22 preoperatively to 3.48 ± 1.57 1 year after surgery in the L_0 group and from 7.3 ± 1.9 to 1.82 ± 1.34 in the L_1 group. The VAS score for low back pain was significantly lower in the L_1 group ($p<0.001$) 1 year after surgery. The VAS score for low back pain was also significantly lower in the L_1 group than in the L_0 group at 1 month and 6 months postoperatively ($p<0.05$), but this difference was not significant at 3 months postoperatively. Similarly, the VAS score for pain radiating to the lower limbs improved significantly in both groups, with the mean score rising from 7.34 ± 2.08 preoperatively to 2.27 ± 1.61 one year postoperatively in the L_0 group, and from 7.54 ± 2.18 preoperatively to 0.73 ± 1.29 one year postoperatively. The difference between the groups at 1-year post-op was statistically significant ($p<0.001$). Statistical analysis did not identify a significant difference between the groups in the VAS score for radiating pain at 1, 3 and 6 months postoperatively.

The ODI score also improved significantly in both study groups postoperatively, from 51.79 % ± 15.22 % preoperatively to 24.06 % ± 12.28 % one year postoperatively in the L_0 group and from 46.45 % ± 15.77 % to 11.51 % ± 8.66 % in the L_1 group, with the difference having high statistical significance ($p < 0.001$) (Figure 4.2). There was also a significant difference in the ODI score between the groups at 1 month ($p<0.001$) and 6 months ($p<0.001$), with greater functional improvement in the L_1 group.

The quality of life associated with the patient's physical and mental health was assessed using the SF-12 self-assessment questionnaire. The summary of the mental component (MCS) of the SF-12 score increased from 39.15 ± 10.89 preoperatively to 51.05 ± 9.2 one year postoperatively in the L_0 group and from 42.01 ± 12.19 to 54.84 ± 7.15 1 year after the operation in the L_1 group. The difference between the groups was statistically significant ($p<0.05$) statistically significant. There was also a significant difference between the study groups at 6 months post-op. However, there was no difference between the groups at 1 and 3 months postoperatively. At the same time,

the physical component (PCS) of the SF-12 score improved from 27.15 ± 7.33 preoperatively to 37.41 ± 8.09 post-op in the L_0 group and from 27.58 ± 7.43 to 46.34 ± 7. 39 in the L_1 group, at one-year postoperative follow-up point, with the difference between the groups being statistically significant ($p < 0.001$). The improvement in the physical component of the SF-12 score was significantly greater in the L_1 group and at 1, 3 and 6 months after the operation ($p < 0.05$).

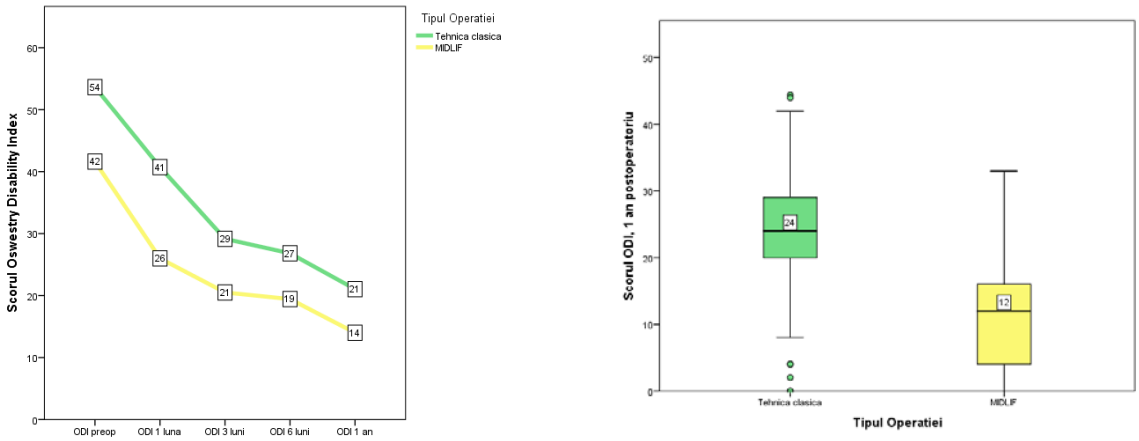

Fig. 3. Postoperative disability improvement ($p < 0.05$ at 1, 6 and 12 months after surgery)

Patient satisfaction was assessed one year after operation. Thirty-seven patients (84.1%) in group L_0 and 48 patients (96.0%) in group L_1 were satisfied with the treatment. This difference was not statistically significant according to the Chi-Square test ($p = 0.050$) and the Fisher test.

Table 1. Parameters associated with surgical morbidity

Surgical parameter	**Group L_0**		**Group L_1**		**x^2, gl = 1, p**
Need for blood transfusion (no., %)	19 patients	33.9%	8 patients	14.3%	<0.05
Haemorrhage (ml)	1026.79 ± 600.6		416.07 ± 273.21		<0.001
Duration of operation (min)	333.16 ± 82.23		294.93 ± 50.45		0.04
Length of hospitalisation (days)	11.48 ± 5.12		10.96 ± 2.90		0.51
Incision length (cm)	17.46 ± 3.79		6.27 ± 2.31		<0.001
Post-op muscle CK increase	576.87 ± 558.98		163.43 ± 353.37		0.04

Analysis of surgical morbidity included intraoperative bleeding, need for blood transfusion, duration of operation, length of hospitalisation, length of incision and increase in serum creatine kinase (CK) concentration after surgery. Group L_1 was associated with better outcomes than group L_0 in terms of intraoperative bleeding volume ($p < 0.001$), need for blood transfusion ($p < 0.05$), duration of operation ($p < 0.05$), incision length ($p < 0.001$) and increase in creatine kinase ($p < 0.05$), calculated as the difference between postoperative CK and preoperative CK (table 2).

Intraoperative and postoperative complications did not differ significantly between groups (table 3). No mechanical complications such as fracture of the pars or pedicle during screw insertion, migration of the screw or cage, or fracture of the screw were recorded in any of the study groups.

There were also no cases of screw malposition. However, there were cases of accidental injury to the dura mater in both groups (5 cases in the control group and 4 cases in the research group), with one patient in group L_1 having a CSF leak through the postoperative wound and one patient in group L_0 having a superficial wound infection. These two complications (CSF leakage,

wound infection) were resolved without revision surgery. Only one patient in the L_0 group developed persistent neuropathic radicular pain. One patient in each study group developed adjacent level disease 5 years after surgery in the L_1 group and 2 years after surgery in the L_0 group. Both patients underwent minimally invasive decompression surgery without interbody fusion. With regard to the overall complication rate, the difference between the study groups was not statistically significant.

Table 2. Perioperative complication rates

Complication	Group L_0		Group L_1		x^2, gl = 1, p
Durotomy	5	8.9%	4	7.1%	0.72
CSF leakage	0	0	1	1.8%	0.31
Wound infection	1	1.8%	0	0	0.31
Reoperations	0	0	0	0	1.0
Deep vein thrombosis	2	3.6%	0	0	0.15
Adjacent level disease	1	1.8%	1	1.8%	1.0

Neuronavigation reduced the exposure to radiation of patients and medical personnel. To determine whether this reduction was statistically significant, data on patient irradiation dose and irradiation time were collected from the intraoperative fluoroscopy device and compared with literature data. The patient irradiation dose was recorded as the product of the dose and the area of exposure to radiation (DAP = dose area product) measured in cGy·cm2 and the fluoroscopy time (FT) in seconds. The data obtained were compared between the study groups and then with those from a multicentre study of patient exposure to radiation during insertion of a conventional trajectory TPd screw [6]. Radiation dose and fluoroscopy time were similar in both study groups ($p>0.05$). A one-sample t-test was used for comparison with literature data. The mean DAP in the multicentre study was 763 cGy·cm2 and 102 seconds for fluoroscopy time. The mean DAP dose for patients in both groups in our study was 393.91 ± 329.09 cGy·cm2. Compared with literature data, there was a difference of 369.08 cGy·cm2, which was statistically significant ($p < 0.001$). The mean fluoroscopy time in our study was 30.83 ± 26.68, with 71. 17 seconds less than in the reference study, a statistically significant difference ($p < 0.001$). Thus, the use of neuronavigation for pedicle screw insertion more than halved the radiation dose and exposure time.

Table 3. Exposure to radiation in comparison to the reference study

Analysed parameter	Our study	Reference study	x^2, gl = 1, p
DAP (cGy·cm2)	178.79 ± 151.99	763	< 0.001
FT (seconds)	12.64 ± 11.38	102	< 0.001

Considering that at the beginning of the learning curve there was a mistrust of the safety of neuronavigation and a tendency to check radiographically each placed screw, the radiation dose to which the patient was exposed remained fairly high. However, towards the end of the study, the use of fluoroscopy was limited to spine level confirmation at the beginning of operation and for final assessment of the screws and interbody cage position at the very end of the operation. Evaluating our data collected only for the last two years (2020 and 2021), we obtained a mean DAP value of 178.79 ± 151.99 cGy·cm2 and a FT value of 12.64 ± 11.38 sec (table 4). Compared to baseline, the mean radiation dose per patient decreased by 584.20 cGy·cm2, a 4-fold decrease ($p<0.001$), and the radiation time decreased by 89.36 seconds, an 8-fold decrease ($p<0.001$). In the case of the fluoroscopy-guided MIDLIF technique, which is associated with disproportionately

high patient exposure to radiation compared with traditional techniques due to the need for simultaneous control of screw insertion in two projections, the advantages of using neuronavigation could be further enhanced. Unfortunately, it was not possible to perform this statistical analysis as all cases of MIDLIF arthrodesis were performed by us using neuronavigation.

GENERAL CONCLUSIONS

The study conducted to determine the clinical and radiological efficacy of the midline lumbar interbody fusion (MIDLIF) with neuronavigation-guided cortical bone trajectory screws, applied exclusively in the treatment of degenerative spondylolisthesis, reached the following conclusions:

1. The success rate of intervertebral fusion after MIDLIF (89.3%) is similar to the traditional arthrodesis techniques (83,9%).
2. Comparative statistical analysis demonstrated a significant superiority of the MIDLIF technique over traditional arthrodesis in terms of postoperative improvement of the local and radicular pain (expressed by the VAS score), reduction in functional disability (Oswestry Disability Index score) and improvement in quality of life associated with the patient's physical and mental health status (SF-12 score).
3. Our study showed that the surgical morbidity associated with the MIDLIF technique is significantly lower than that of conventional intervertebral arthrodesis. The MIDLIF technique is associated with a much lower rate of bleeding complications. Intraoperative bleeding volume was significantly higher with traditional fusion techniques (1026 ml vs. 416 ml, $p < 0.001$). The number of patients requiring blood transfusions was also significantly higher with traditional techniques (33.9% vs. 14.3%, $p < 0.05$). In addition, MIDLIF was associated with significantly shorter surgical times (295 min vs. 333 min, $p < 0.05$) and a much shorter skin incision (6.27 cm vs. 17.46 cm, $p < 0.001$). Surgical trauma to muscle tissue, expressed as increased serum creatine kinase level, was significantly lower with MIDLIF arthrodesis (163 vs. 576 U/L, $p < 0.05$), thus confirming its minimally invasive nature. The overall rate of perioperative complications was similar for both studied surgical techniques.
4. Intraoperative neuronavigation is a highly effective technical modality of guiding pedicle screw insertion in both the traditional and CBT trajectories. The application of neuronavigation to the patients included in the scientific study resulted in a high precision of screw placement, with a zero-malposition rate. The use of neuronavigation also led to a significant reduction in the radiation dose and duration of patient exposure to radiation.

The standard method of guiding pedicle screw insertion using spinal neuronavigation is not valid for MIDLIF arthrodesis, due to the specific trajectory of CBT screws. The intraoperative neuronavigation setup can be optimized for transcortical pedicle screw insertion by implementing a modified dynamic reference array fixation procedure.

5. The results of the study were used to develop and scientifically justify an optimized algorithm for the radiological evaluation and surgical treatment of patients with degenerative lumbar spondylolisthesis, including new technical modalities (spinal neuronavigation, CBT pedicle screws, MIDLIF arthrodesis, minimally invasive “over the top” spinal decompression). Based on this algorithm, the institutional clinical protocol for the diagnosis and treatment of degenerative lumbar spondylolisthesis was recorded and implemented in practice.

SELECTIVE BIBLIOGRAPHY

1. Choudhri TF, Mummaneni PV, Dhall SS, et al. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 4: radiographic assessment of fusion status. J Neurosurg Spine. 2014; 21(1): 23-30. ISSN 1547-5646. doi: 10.3171/2014.4.spine14267. PMID: 24980581.

2. Elmekaty M, Kotani Y, Mehy EE, et al. Clinical and Radiological Comparison between Three Different Minimally Invasive Surgical Fusion Techniques for Single-Level Lumbar Isthmic and Degenerative Spondylolisthesis: Minimally Invasive Surgical Posterolateral Fusion versus Minimally Invasive Surgical Transforaminal Lumbar Interbody Fusion versus Midline Lumbar Fusion. Asian Spine J. 2018; 12(5): 870-879. ISSN 1976-1902. doi: 10.31616/asj.2018.12.5.870. PMID: 30213170.

3. Glennie RA, Dea N, Kwon BK, et al. Early clinical results with cortically based pedicle screw trajectory for fusion of the degenerative lumbar spine. J Clin Neurosci. 2015; 22(6): 972-975. ISSN 0967-5868. doi: 10.1016/j.jocn.2015.01.010. PMID: 25769253.

4. Hu JN, Yang XF, Li CM, et al. Comparison of cortical bone trajectory versus pedicle screw techniques in lumbar fusion surgery: A meta-analysis. Medicine (Baltimore). 2019; 98(33): e16751. ISSN 1536-5964 doi: 10.1097/MD.0000000000016751. PMID: 31415372.

5. Kolz JM, Pinter ZW, Bydon M, et al. Controversies in Spine Surgery: Is a Cortical Bone Trajectory Superior to Traditional Pedicle Screw Trajectory? Clin Spine Surg. 2020. ISSN 2380-0186. doi: 10.1097/bsd.0000000000000965. PMID: 32205518.

6. Kouyoumdjïan P, Gras-Combe G, Grelat M, et al. Surgeon's and patient's radiation exposure during percutaneous thoraco-lumbar pedicle screw fixation: A prospective multicenter study of 100 cases. Orthop Traumatol Surg Res. 2018; 104(5): 597-602. ISSN 1877-0568. doi: 10.1016/j.otsr.2018.05.009. PMID: 29969721.

7. Lee GW, Son JH, Ahn MW, et al. The comparison of pedicle screw and cortical screw in posterior lumbar interbody fusion: a prospective randomized noninferiority trial. The spine journal : official journal of the North American Spine Society. 2015; 15(7): 1519-1526. ISSN 1878-1632. doi: 10.1016/j.spinee.2015.02.038. PMID: 25728553.

8. Lee GW, Ahn MW. Comparative Study of Cortical Bone Trajectory-Pedicle Screw (Cortical Screw) Versus Conventional Pedicle Screw in Single-Level Posterior Lumbar Interbody Fusion: A 2-Year Post Hoc Analysis from Prospectively Randomized Data. World Neurosurg. 2018; 109: e194-e202. ISSN 1878-8750. doi: 10.1016/j.wneu.2017.09.137. PMID: 28966154.

9. Li HM, Zhang RJ, Gao H, et al. Biomechanical Fixation Properties of the Cortical Bone Trajectory in the Osteoporotic Lumbar Spine. World Neurosurg. 2018; 119: e717-e727. ISSN 1878-8750. doi: 10.1016/j.wneu.2018.07.253. PMID: 30092463.

10. Marengo N, Ajello M, Pecoraro MF, et al. Cortical Bone Trajectory Screws in Posterior Lumbar Interbody Fusion: Minimally Invasive Surgery for Maximal Muscle Sparing-A Prospective Comparative Study with the Traditional Open Technique. Biomed Res Int. 2018; 2018: 7424568. ISSN 2314-6141 doi: 10.1155/2018/7424568. PMID: 29670905.

11. Matsukawa K, Yato Y, Kato T, et al. In vivo analysis of insertional torque during pedicle screwing using cortical bone trajectory technique. Spine. 2014; 39(4): E240-245. ISSN 0362-2436. doi: 10.1097/brs.0000000000000116. PMID: 24253778.

12. Matsukawa K, Yato Y, Imabayashi H, et al. Biomechanical evaluation of the fixation strength of lumbar pedicle screws using cortical bone trajectory: a finite element study. J

Neurosurg Spine. 2015; 23(4): 471-478. ISSN 1547-5646. doi: 10.3171/2015.1.spine141103. PMID: 26161515.

13. Matsukawa K, Yato Y, Hynes RA, et al. Comparison of Pedicle Screw Fixation Strength Among Different Transpedicular Trajectories: A Finite Element Study. Clin Spine Surg. 2017; 30(7): 301-307. ISSN 2380-0186. doi: 10.1097/bsd.0000000000000258. PMID: 28746125.

14. Mizuno M, Kuraishi K, Umeda Y, et al. Midline lumbar fusion with cortical bone trajectory screw. Neurol Med Chir (Tokyo). 2014; 54(9): 716-721. ISSN 0470-8105. doi: 10.2176/nmc.st.2013-0395. PMID: 25169139.

15. Oshino H, Sakakibara T, Inaba T, et al. A biomechanical comparison between cortical bone trajectory fixation and pedicle screw fixation. J Orthop Surg Res. 2015; 10: 125. ISSN 1749-799x. doi: 10.1186/s13018-015-0270-0. PMID: 26275401.

16. Perez-Orribo L, Kalb S, Reyes PM, et al. Biomechanics of lumbar cortical screw-rod fixation versus pedicle screw-rod fixation with and without interbody support. Spine. 2013; 38(8): 635-641. ISSN 0362-2436. doi: 10.1097/BRS.0b013e318279a95e. PMID: 23104197.

17. Phan K, Ramachandran V, Tran TM, et al. Systematic review of cortical bone trajectory versus pedicle screw techniques for lumbosacral spine fusion. J Spine Surg. 2017; 3(4): 679-688. ISSN 2414-4630. doi: 10.21037/jss.2017.11.03. PMID: 29354747.

18. Sakaura H, Miwa T, Yamashita T, et al. Posterior lumbar interbody fusion with cortical bone trajectory screw fixation versus posterior lumbar interbody fusion using traditional pedicle screw fixation for degenerative lumbar spondylolisthesis: a comparative study. J Neurosurg Spine. 2016; 25(5): 591-595. ISSN 1547-5646. doi: 10.3171/2016.3.spine151525. PMID: 27231813.

19. Sakaura H, Miwa T, Yamashita T, et al. Cortical bone trajectory screw fixation versus traditional pedicle screw fixation for 2-level posterior lumbar interbody fusion: comparison of surgical outcomes for 2-level degenerative lumbar spondylolisthesis. J Neurosurg Spine. 2018; 28(1): 57-62. ISSN 1547-5646. doi: 10.3171/2017.5.spine161154. PMID: 29125430.

20. Santoni BG, Hynes RA, McGilvray KC, et al. Cortical bone trajectory for lumbar pedicle screws. The spine journal : official journal of the North American Spine Society. 2009; 9(5): 366-373. ISSN 1529-9430. doi: 10.1016/j.spinee.2008.07.008. PMID: 18790684.

21. Shah RR, Mohammed S, Saifuddin A, et al. Comparison of plain radiographs with CT scan to evaluate interbody fusion following the use of titanium interbody cages and transpedicular instrumentation. Eur Spine J. 2003; 12(4): 378-385. ISSN 1432-0932. doi: 10.1007/s00586-002-0517-4.

22. Takenaka S, Mukai Y, Tateishi K, et al. Clinical Outcomes After Posterior Lumbar Interbody Fusion: Comparison of Cortical Bone Trajectory and Conventional Pedicle Screw Insertion. Clin Spine Surg. 2017; 30(10): E1411-e1418. ISSN 2380-0186. doi: 10.1097/bsd.0000000000000514. PMID: 28266955.

23. Wang J, He X, Sun T. Comparative clinical efficacy and safety of cortical bone trajectory screw fixation and traditional pedicle screw fixation in posterior lumbar fusion: a systematic review and meta-analysis. 2019. ISSN 0940-6719. doi: 10.1007/s00586-019-05999-y. PMID: 31087165.

LIST OF PUBLICATIONS

and scientific events where research results have been presented

SCIENTIFIC PAPERS

- **Articles in accredited national scientific journals:**

  ✓ **Articles in category B journals**

1. **Borodin, S**. Fixarea segmentară internă a coloanei vertebrale cu șuruburi pediculare transcorticale. Revista literaturii. In: *Buletinul Academiei de Ştiinţe a Moldovei. Ştiinţe Medicale.* 2017, vol. 3(55), pp. 198-205. ISSN 1857-0011

1. **Borodin, S.** Clinical efficacy of MIDLIF arthrodesis with neuronavigation-guided cortical bone trajectory screws in the treatment of degenerative lumbar spondylolisthesis: a prospective randomized controlled trial. In: *Moldovan Journal of Health Sciences (Revista de Ştiinţe ale Sănătăţii din Moldova)*. 2023, vol. 10(1), pp. 9-15. ISSN 2345-1467. https://doi.org/10.52645/MJHS.2023.1.02
2. **Borodin, S.** Delayed successful interbody fusion after initially failed midline lumbar interbody fusion spinal arthrodesis in a patient with degenerative lumbar spondylolisthesis and severe osteoporosis. In: *Revista de Ştiinţe ale Sănătăţii din Moldova*. 2023, vol. 10 (2), pp. 54-60. ISSN 2345-1467. DOI: 10.52645/MJHS.2023.2.09

- **Articles in international scientific collections:**

3. **Borodin, S**. Midline Lumbar Interbody Fusion (MIDLIF) with Cortical Bone Trajectory Pedicle Screws, Used in The Treatment of Degenerative Disk Disease. *OMI - Salzburg Medical Seminars Online Case Library and OMI Handbook Online.* Available at: https://mhb.openmedicalinstitute.org/media/2017/608/main/data/lectures/608_bo/index.html Publication in the OMI Salzburg Medical Seminars (Online Case Library) and the OMI Handbook Online

- **Abstracts/thesis in the proceedings of national and international scientific conferences**

4. **Borodin, S.**; Sumleanschi, A.; Bodiu, A. Early Clinical Results with the Midline Lumbar Interbody Fusion Using Cortical Bone Trajectory Pedicle Screws. In: *Turk Neurosurg.* 2017; 27 (Supplement), p. 259. ISSN 1019-5149 - NLM ID 9423821
5. **Borodin, S.**; Sumleanschi, A.; Bodiu, A. Первичный опыт применения транскортикальной костной траектории транспедикулярных винтов с использованием спинальной нейронавигации при хирургическом лечении поясничного дегенеративного спондилолистеза. In: *The 1st Russian Congress of Functional and Stereotactic Surgeons Abstract Book.* 2016, p. 16.
6. Bodiu, A.; **Borodin, S.**; Sumleanschi, A. Our early experience with the use of BrainLab Curve neuronavigation system in the Midline Lumbar Interbody Fusion (MIDLIF) procedure, for the surgical treatment of the degenerative spondylolisthesis. In: *Ukrainian Neurosurgery Conference "Traumatic injuries of the central and peripheral nervous system" Abstract Book*, 2016, p. 118.
7. **Borodin, S.**; Bodiu, A.; Eftodiev, E.; Sumleanschi, A.; Cotorcea, I. Clinical and radiological features of cortical bone trajectory pedicle screw fixation of lumbar spine. In: *The Moldovan Medical Journal.* 2018, vol. 61, RMI Congress Issue, p. 70. ISSN 2537-6381
8. **Borodin, S.**; Sumleanschi, A. Early clinical results with the cortical bone trajectory pedicle screw fixation of the lumbar spine, used for the surgical treatment of the degenerative spondylolisthesis. In: *MedEspera: the 6th Internat. Medical Congress for Students and Young Doctors: abstract book*. Chișinău: S. n., 2016, pp. 169-170.

9. **Borodin, S.**; Bobeico, S.; Sumleanschi Alexandru. The lumbar interbody fusion using cortical bone trajectory pedicle screws: clinical results of the lumbar degenerative spondylosis surgical treatment. In: *MedEspera International Medical Congress for Students and Young Doctors: abstract book*. Chisinau, Republic of Moldova: 2018, pp. 117-118.
10. **Borodin, S.**; Sumleanschi, A.; Bezer, M. Clinical and radiological outcomes comparison of the posterior lumbar interbody fusion with cortical bone trajectory screw fixation (MIDLF) and conventional pedicle screw fixation for low-grade degenerative spondylolisthesis. In: *MedEspera International Medical Congress for Students and Young Doctors*: abstract book. Chisinau, Republic of Moldova: 2020, pp. 72-73. ISBN 978-9975-151-11-5.
11. Zapuhlih, G.; **Borodin, S.**; Bostan A. The first-year experience in the spinal instrumentation neurosurgery - from microneurosurgery to the spinal neurosurgery. Romanian Neurosurgery. Selected abstracts of the 39th Congress of the Romanian Society of Neurosurgery with International Participation. 2013, vol. 20(4), pp. 412-413. ISSN 1220-8841.

- **Patents, registration certificates, materials at trade fairs**

12. **Borodin, S.;** Bodiu, A. Implementation of the midline lumbar interbody fusion (MIDLIF) with CBT pedicle screws in the surgical treatment of degenerative spinal disorders. Innovator Certificate No. 5806 of 14.12.2020
13. **Borodin, S.;** Bodiu A. Stereotactic neuronavigation-guided transpedicular and cortico-pedicular trajectory screw insertion technique. Certificate of Innovator No. 5813 of 20.12.2020.
14. **Borodin, S.;** Bodiu, A. Implementation of intraoperative neurophysiological monitoring technique in lumbar intervertebral arthrodesis operations with pedicle screws. Certificate of Innovator No. 5817 of 04.01.2021.
15. **Borodin, S.;** Bodiu A.; Bobeico, S. Implementation of the minimally invasive technique of bilateral tubular ("over the top") decompression of the spinal canal by unilateral laminotomy in the surgical treatment of degenerative lumbar spondylolisthesis. Innovator Certificate No. 5832 of 09.03.2021
16. **Borodin, S.;** Bodiu, A. Optimization of the neuronavigation system reference array fixation procedure in MIDLIF lumbar interbody arthrodesis. Certificate of registration of copyright and related rights. Series O No. 6916 of 02.06.2021.
17. **Borodin, S.;** Bodiu, A.; Șumleanschi, A.; Gherman, I.; Eftodiev, E. Implementation of transcortical pedicle screw trajectories in segmental internal fixation of the lumbar spine. Certificate of Innovator No. 02/19 of 23.12.2019.
18. **Borodin, S.;** Bodiu, A.; Șumleanschi, A.; Gherman, I.; Eftodiev, E. Intraoperative imaging guidance of transcortical pedicle screws using stereotactic spinal neuronavigation. Innovator Certificate No. 03/19 of 23.12.2019
19. **Borodin, S.;** Bodiu, A.; Șumleanschi, A.; Gherman, I.; Eftodiev, E. Implementation of the Midline Lumbar Intervertebral Fusion technique used in the surgical treatment of degenerative spondylolisthesis. Certificate of Innovator No. 01/19 of 23.12.2019

- **Participations with communications at scientific forums:**

✓ **Internaţional**

20. **Borodin, S.** The first-year experience in the spinal instrumentation neurosurgery - from microneurosurgery to the spinal neurosurgery. *The 39th Congress of the Romanian Society of Neurosurgery with International Participation.* Bucharest, Romania. September 18-21, 2013.
21. **Borodin, S.** Первичный опыт применения транскортикальной костной траектории транспедикулярных винтов с использованием спинальной нейронавигации при

хирургическом лечении поясничного дегенеративного спондилолистеза. *The 1st Russian Congress of Functional and Stereotactic Surgeons.* Moscow, Russian Federation. March 17-18, 2016.

22. **Borodin, S.** Our early experience with the use of BrainLab Curve neuronavigation system in the Midline Lumbar Interbody Fusion (MIDLIF) procedure, for the surgical treatment of the degenerative spondylolisthesis. *Ukrainian Neurosurgery Conference "Traumatic injuries of the central and peripheral nervous system".* Kamianets-Podilskyi, Ukraine. September 15-16, 2016.
23. **Borodin, S.** Early clinical results with the cortical bone trajectory pedicle screw fixation of the lumbar spine, used for the surgical treatment of the degenerative spondylolisthesis. *MedEspera: the 6th Internat. Medical Congress for Students and Young Doctors*. Chișinău, May 12-14, 2016.
24. **Borodin, S.** Early Clinical Results with the Midline Lumbar Interbody Fusion Using Cortical Bone Trajectory Pedicle Screws. *XVI WFNS World Congress of Neurosurgery, Istanbul, Turkey. August 20-25, 2017.*
25. **Borodin, S.** Midline Lumbar Interbody Fusion (MIDLIF) with Cortical Bone Trajectory Pedicle Screws, Used In The Treatment of Degenerative Disk Disease". *Open Medical Institute Salzburg Weill Cornell Neurosurgery (Spine) Seminar.* Salzburg, Austria. June 4 - 10, 2017.
26. **Borodin, S.** The lumbar interbody fusion using cortical bone trajectory pedicle screws: clinical results of the lumbar degenerative spondylosis surgical treatment. *MedEspera: the 7th International Medical Congress for Students and Young Doctors*. Chisinau, May 3-5, 2018.
27. **Borodin, S.** Clinical and radiological outcomes comparison of the posterior lumbar interbody fusion with cortical bone trajectory screw fixation (MIDLF) and conventional pedicle screw fixation for low-grade degenerative spondylolisthesis. *MedEspera: the 8th International Medical Congress for Students and Young Doctors*. Chisinau, September 24-26, 2020.

✓ **National**

28. **Borodin, S.** Tratamentul chirurgical contemporan al spondilolistezisului lombar. *Conferința științifico-practică cu genericul: „Managementul Modern În Reabilitarea Medicală Neurologică"*. Bălți, 6 February 2017.