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Recommendations for preventing postoperative complications of transpedicular screw fixation in patients with spinal disorders

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Innovations in spinal surgery have improved technical precision and perioperative efficiency, however, the issue of postoperative complications arising from the use of transpedicular screw fixation (TF) remains a concern. Objective. To develop an algorithmic protocol for reducing the likelihood of postoperative complications in patients undergoing transpedicular screw fixation. Methods. An analysis was conducted of the surgical outcomes of 2,760 patients with degenerative diseases, injuries and deformities of the spine, with radiographic assessment of transpedicular screw (TS) placement, both with and without the use of a 3D navigation system. The patients' laboratory parameters and the results of 62 intraoperative neurophysiological monitoring sessions were studied. Results. An algorithmic scheme was developed to prevent the development of TS complications and improve the quality of care for patients with spinal disorders: preoperative strategic comprehensive planning, intraoperative monitoring and techniques for precise TS placement, postoperative follow-up, prevention complications. An algorithm for action has been defined in cases of suspicion of an incorrectly placed screw or deterioration in neurological status. The core of the prediction and assessment of the likelihood of postoperative complications is an algorithmized scheme for laboratory examination of patients. Its suitability was verified during the surgical treatment of 30 patients. Conclusions. The algorithm-based protocol developed enables a structured assessment of the risk of complications, the planning of surgical treatment taking into account modern technologies, the monitoring of all critical points, the implementation of an individualized approach for each patient, and the integration of spinal navigation and neuromonitoring of the surgical process, which will minimize complications and have a positive impact on patients' condition, the length of their hospital stay, and the quality of treatment outcomes.

Інновації в хірургії хребта підвищили технічну точність і періопераційну ефективність, проте проблема післяопераційних ускладнень через застосування транспедикулярної фіксації (ТФ) залишається актуальною. Мета. Розробити алгоритмізовану схему зниження вірогідності розвитку післяопераційних ускладнень у пацієнтів із використанням транспедикулярної фіксації. Методи. Проведено аналіз результатів операцій 2 760 пацієнтів із дегенеративними захворюваннями, травмами та деформаціями хребта з рентгенологічною оцінкою введення транспедикулярних гвинтів (ТГ), без та з допомогою 3D-навігаційної системи. Вивчено лабораторні показники пацієнтів і результати 62 інтраопераційних нейрофізіологічних моніторингів. Результати. Складено алгоритмізовану схему для попередження розвитку ускладнень ТФ і підвищення якості лікування хворих із захворюваннями хребта: передопераційне стратегічне комплексне планування, інтраопераційний контроль і техніка точного встановлення ТГ, післяопераційне спостереження та профілактика ускладнень. Визначено алгоритм дії за підозри на неправильно встановлений гвинт або погіршення неврологічного статусу. Ядром предикції й оцінки вірогідності розвитку післяопераційних ускладнень є алгоритмізована схема лабораторного обстеження пацієнтів. Її придатність перевірено під час хірургічного лікуванняі 30 хворих. Висновки. Розроблена алгоритмізована схема дозволяє структуровано оцінити ризик ускладнень, запланувати хірургічне лікування з урахуваннях сучасних технологій, проконтролювати усі критичні точки, здійснити індивідуальний підхід до кожного пацієнта й інтеграцію спінальної навігації, нейромоніторинг операційного процесу, що дозволить мінімізувати ускладнення та позитивно впливатиме на стан пацієнтів, тривалість їхнього перебування в стаціонарі, покращення якості результатів лікування. Ключові слова. Хребет, грудний відділ, поперековий відділ, транспедикулярна фіксація, ускладнення, лабораторні показники.

Key words. Spine, thoracic section, lumbar section, transpedicular fixation, complication, prevention, biochemistry, immunology

Introduction

Spinal fusion with transpedicular fixation (TPF) is considered the most frequently performed procedure in orthopedic practice, although it may be accompanied by complications that require re-intervention [1, 2].

Incorrect placement of transpedicular screws (TPS) is a major cause of neurological, vascular, visceral complications, as well as cerebrospinal fluid leakage. The average frequency of incorrect TPS placement in various studies ranges from 0–2 % to 25–95 % in patients with scoliosis and about 4.2% of cases in patients with degenerative spine diseases [1–3].

Among patients experiencing complications, body mass index (BMI) frequently exceeds 25 kg/m², reflecting a lower initial health status as measured by the SF-36 scale and a disrupted lumbopelvic balance. These factors contribute to extended hospital stays, an increased number of TPS levels, and consequently, less optimal postoperative frontal and sagittal correction [5]. H. E. Goheer et al. noted that with each unit increase in a patient's BMI, the time required for posterior lumbar spinal fusion increased by 0.84 minutes. At the same time, the likelihood of complications related to the surgical wound increased by 19.7% after posterior spinal fusion at one level [6].

The presence of the upper instrumented vertebra at the apex of the kyphosis, preoperative sagittal lumbopelvic imbalance, and osteoporosis have been identified as significant risk factors for complications in patients with degenerative lumbar scoliosis and concomitant thoracolumbar kyphosis. Surgical planning for this condition should account for spinal morphology to avoid positioning the upper instrumented vertebra at the kyphosis apex [4–6].

Advances in spinal surgery have increased precision and efficiency, yet complications with TPF procedures remain a significant concern and are the focus of this study. We believe it is important to analyze the data from the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the NAS of Ukraine regarding surgeries performed with transpedicular fixation, as well as to investigate the causes of complications and adverse outcomes, and to systematize the results of clinical and laboratory findings.

Purpose: To develop an algorithmic method to reduce the likelihood of postoperative complications in patients undergoing spinal transpedicular fixation.

Material and Methods

The study was conducted at the Spine Pathology Clinic of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the NAS of Ukraine. It was approved by the local bioethics committee of this institution (protocol No. 257 dated 22.12.2025) and carried out in compliance with the principles of good clinical practice (ICH GCP), the Helsinki Declaration on Human Rights and Biomedicine (1977 edition), as well as the requirements of current Ukrainian legislation. All patients involved in the study were properly informed about the purpose, plan, and conditions of the study and provided written informed consent for participation.

A retrospective and prospective analysis was conducted on the results of surgical interventions in 2,760 patients between 2004 and 2018, due to degenerative diseases, traumatic injuries, and deformities of the thoracic and lumbar spine, all of whom underwent transpedicular fixation of the vertebrae at these locations. Revision surgeries were carried out on 268 patients. Among these, complications associated with transpedicular constructions (TPC), including those caused by transpedicular screws (TPS), rods, or combined systems, were examined in 143 cases. The accuracy of TPS placement in vertebrae was compared using radiological examinations (frontal, sagittal), computed tomography (CT), and magnetic resonance imaging (MRI). The number of revision surgeries directly linked to improper screw placement was analyzed between Group I, using the standard screw placement technique (free-hand technique) (2,128 patients, 12,879 screws), and Group II, which utilized a 3D navigation system based on preoperative CT (632 patients, 3,203 screws). Additionally, 62 results of intraoperative neurophysiological monitoring (IONM) were analyzed.

At the same time, clinical-laboratory, biochemical, and immunological blood tests of these patients were studied prior to treatment, and their diagnostic sensitivity was determined. Among these, the following were evaluated: hemoglobin content, total bilirubin (TB), total glycoproteins (GP), haptoglobin (HP), C-reactive protein (CRP), alkaline and acid phosphatase activities (ALP and ACP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), fibrinogen (FG), D-dimers, soluble fibrin-monomer complexes (SFMC), circulating immune complexes (CIC), activated partial thromboplastin time (APTT), fibrinolytic activity (FA), leukocyte count, erythrocyte sedimentation rate (ESR), and the content and spontaneous migration of lymphocytes (LIF).

Results

The algorithmic approach developed (see Figure 1) facilitated the application of a well-considered protocol to minimize the risk of postoperative and intraopera-

tive complications in patients undergoing decompression-stabilization spinal surgeries.

Preoperative strategic comprehensive planning involves determining indicators before performing decompression-stabilizing surgical interventions using TPF and clarifying risk factors for each specific patient:

– Clinical-diagnostic study — patient history (degenerative diseases, trauma, spinal deformities, tumors, inflammation, osteoporosis, previous surgeries); laboratory (biochemical) examination according to an algorithmized scheme; assessment of comorbid conditions (diabetes, obesity, cardiovascular diseases, hormone therapy);

– Instrumental diagnosis — spinal radiography (frontal, sagittal projections) to determine structure, degree of deformation and its mobility, displacement, instability of vertebrae, and the height of vertebral bodies and intervertebral discs; CT of the spine (individual anatomy of vertebral arches, length, and diameter), identification of intracanalar and other congenital anomalies (diastematomyelia, spondylolysis, defects in vertebral formation and integrity); MRI (study of nerve structures and their compression, intervertebral discs, muscles); densitometry (detection of osteoporosis for correction of intervention tactics);

– Surgical treatment planning — selecting the length of spinal fixation considering segment stability, degree and magnitude of deformation, sagittal contour of the spine, type of disease (degenerative, trauma, tumors, deformities). Extensive instrumentation of the lumbar spine requiring fixation of the L_V–S_I zone necessitates additional fixation to the iliac bones; consideration of bone mineral density (BMD); individual selection of the construction: diameter, length, and type of TPS (mono-, polyaxial, reduction), stiffness of rods, and their length.

Intraoperative Oversight and Precision in TPS Placement

During this phase, it is essential to pay close attention to several key factors:

– preparation and visualization — marking the level planned for surgery using intraoperative radiography and spinal navigation; verifying the intervention plan according to the patient's anatomy; placing electrodes and performing IONM, drawing baseline lines;

– choice of screw placement technique: "free-hand" (using predefined screw entry points based on anatomical landmarks) or under the control of a 3D navigation system, ensuring the necessary conditions to avoid navigation errors (accurate point registration, accounting for the patient's position differences during CT and on the operating table; control of patient positioning, respiratory movements, and antenna displacement on the spinous process after registration; avoiding damage to the reflective coating of the balls on the antenna or instrument);

– work on distant segments of the spine from the site of registration requires special control of the surgical wound to avoid errors in the image display on the monitor;

– TPS monitoring (radiographic control, IONM using as many muscles as possible);

– reducing complication risks (asepsis/antisepsis), monitoring blood loss, preventing neurological damage (monitoring the tools near the dura mater and spinal nerves during screw placement and rod installation, blockers).

Postoperative Monitoring, Prevention, and Rehabilitation

At the early and late postoperative stages, it is necessary to use radiographic studies or CT scans to determine the accuracy of TPS placement in the vertebrae, as well as the formation of the spinal fusion, stability of the transpedicular system, adjacent segments, loss of achieved deformation correction, and neurological status, as well as to provide rehabilitation treatment.

A general action plan in case of suspicion of improperly placed screws or deterioration of neurological status during surgery and after the intervention is shown in Figure 2.

Indications for revision surgery include improper placement of screws resulting in significant pain, neurological deficit, or the detection of an infectious process. These are technically very complex surgeries with uncertain and unguaranteed results. Preoperative, intraoperative, and postoperative monitoring of these patients is more challenging than for patients with primary surgeries. In such cases, preoperative planning is of utmost importance. The decision-making process should address the scope and type of revision surgery, the necessity and extent of spinal segment fixation, sagittal balance correction, type of osteotomy, and its location.

In cases where intraoperative concerns arise regarding the positioning of the TPS, it is imperative to promptly obtain radiographs in both frontal and sagittal projections, accompanied by neuro-monitoring. Based on the results, a decision must be made regarding screw revision. It may also be possible to reposition the screw along the cortical trajectory if it was initially placed using the transpedicular trajectory, and vice versa.

If there is concern regarding potential improper screw placement following surgery, the physician's response will be guided by when the issue becomes

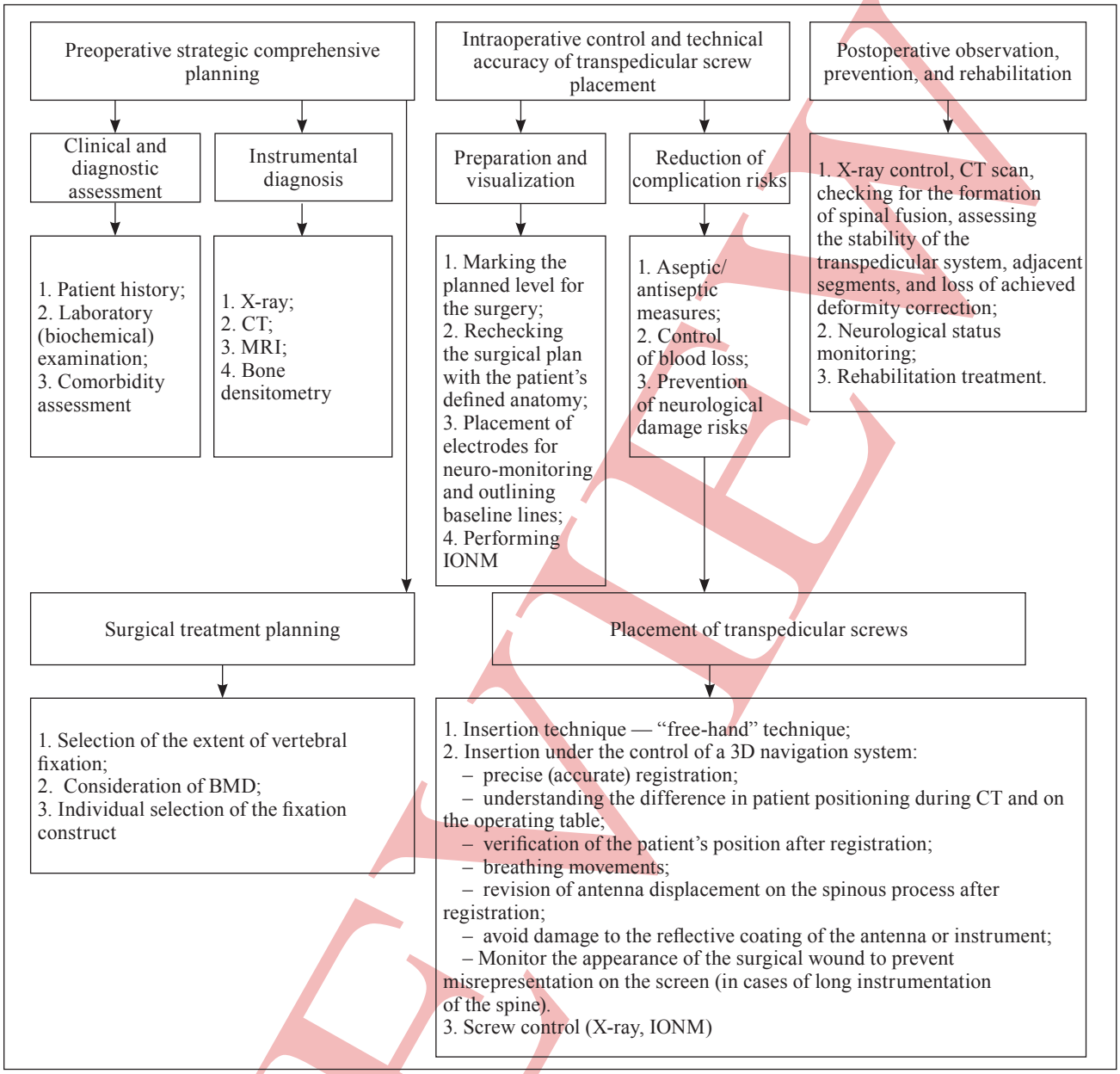

Fig. 1. Algorithmic Methodology for Preventing Postoperative Complications in Transpedicular Spinal Fixation

apparent. If a patient experiences pain or neurological changes, such as numbness in a particular dermatome, a few hours or days after surgery, these symptoms may result from local tissue swelling. In this case, the wound and adjacent tissues should be examined, their temperature and color assessed, and tenderness evaluated. Next stage involves a limited laboratory examination of the patient, namely a clinical and biochemical blood test with a focus on markers of the inflammatory process, such as acute-phase proteins, glycoprotein (GP), and C-reactive protein (CRP). Parallel to this, radiographic examination or CT scan should be performed, as well as a detailed neurological examination and IONM.

If no changes in the patient's status occur within two weeks of observation, revision surgery with screw repositioning is indicated. The presence of an infectious process also indicates the need for revision surgery, which may involve the removal of the entire transpedicular construct.

Case Study

A 64-year-old female patient presented with a diagnosis of postmenopausal osteoporosis (early surgical menopause at 42 years old) and multiple pathological fractures of the thoracic and lumbar vertebrae (Fig. 3, a).

Before undergoing surgery, which was performed on 20.02.2020, a clinical and diagnostic examination

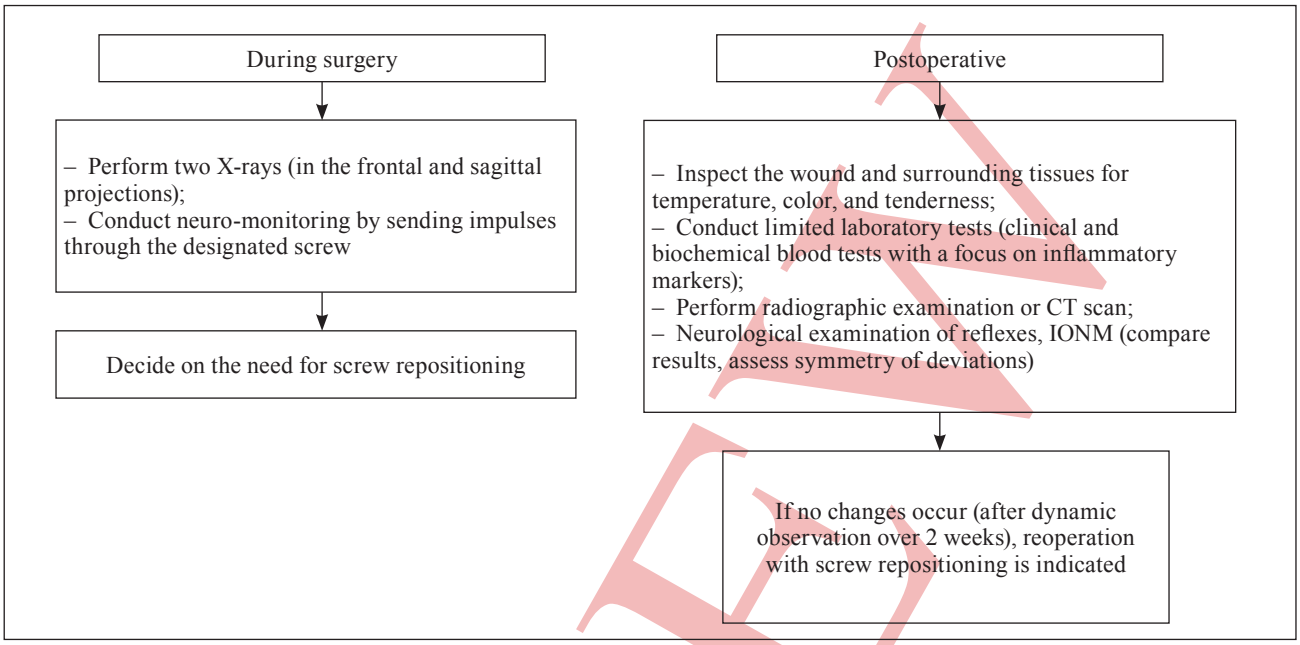

Fig. 2. Algorithm for Action in Case of Suspected Incorrect Screw Placement or Decrease in Neurological Status During Spinal TF Surgery

was conducted. Despite her comorbid status, spinal deformity correction was performed using transpedicular fixation (TPF) at the ThX–SI level, along with allograft spinal fusion.

During post-operative monitoring, one month later, instability of the TPF system and the formation of an adjacent spinal deformity were noted, as indicated by control radiographs (Fig. 3, b). A loss of deformity correction was identified, resulting in destabilization of the transpedicular system. These factors led to a revision procedure for the correct placement of the TPS, involving extension of the spinal instrumentation to the ThIII vertebra at the ThIII–SI level (Fig. 3, c).

Discussion

The scientific literature emphasizes that following spinal fusion using TPF, common complications include residual pain in the operated segment or neuropathic pain. Neuropathic pain is a potential complication of spine surgery with TPF, and it can significantly impair the patient's quality of life. Research shows that neurological issues caused by nerve compression in the lumbar spine may persist even after decompressive-stabilizing surgery, and full recovery is not always achieved [7]. Chronic neuropathic pain after spinal fusion typically does not subside with treatment; it often persists and may even worsen, caused by alterations in the anatomical relationships of the spinal motion segment [8]. This type of pain usually begins before the surgery and remains, or even intensifies, after the procedure. According to the literature, this type of pain syndrome is observed in 5 % to 30 % of patients [9]. In our study, the incidence was 23.9 %.

The torque applied during the tightening of the TPS is crucial. S. Nakamura and colleagues stress the importance of correlating the torque during the tightening of the TPS with the BMD, age, and BMI. This correlation helps predict the stiffness of the fixation and prevents the failure of instruments during lumbar spine fusion surgery. Generally, the torque should remain within specific limits: the lower side is restricted by the minimal force necessary to create the required friction, while the upper limit should not exceed the threshold beyond which bone tissue destruction begins [10–11].

In conclusion, we recommend the use of 3D navigation during the placement of TPS, particularly in complex cases involving long instrumentation for scoliosis deformity stabilization. This aligns with the conclusions of A. R. Kothari et al., who examined the placement of 259 screws in 21 scoliosis patients and found that navigation using the O-arm reduced the frequency of medial and lateral (i.e., “critical”) placement errors of TPS (> 2 mm) [12].

In cases of abnormal laboratory data, consideration should be given to the possibility of infection, either deep or superficial. S. Tummala et al. found that preoperative colonization by methicillin-resistant Staphylococcus aureus significantly increases the risk of mortality, wound complications, systemic infections, hematologic disorders, and acute renal injury following elective lumbar spine surgery [13].

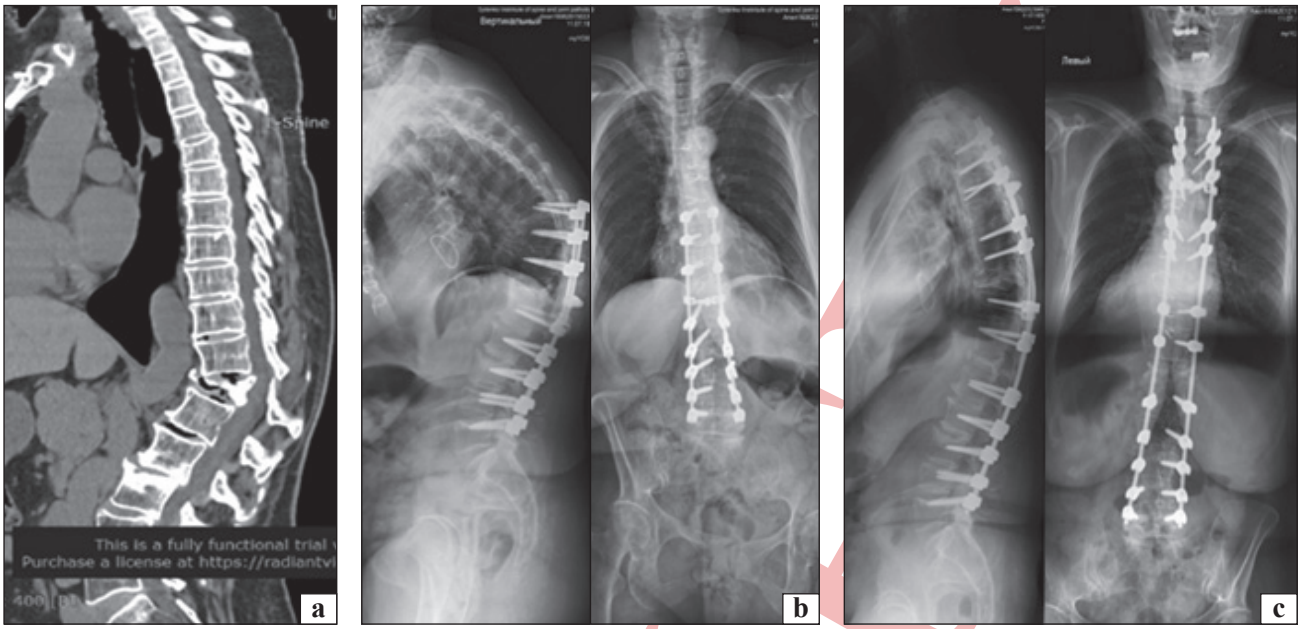

Fig. 3. X-ray Images: a) Before surgery and b) After initial surgery. One month later, c) Revision of the transpedicular system

Creating posterior bone-plastic spinal fusion using TPS provides stabilization of the affected area; however, it simultaneously disrupts the normal biomechanical relationships between the spinal motion segments. This can lead to or accelerate degenerative changes in adjacent spinal segments. Pathological changes in these adjacent areas are manifested by decreased disc height, the formation of hernias, scoliosis deformities, spondylolisthesis, or spinal canal stenosis [14]. Radiological signs of disease in adjacent segments may occur without clinical symptoms in 12.2 % to 42.6 % of cases, while radiological changes with clinical manifestations are observed in 4% to 20% of cases [15].

The surgeon must be prepared to manage accompanying complications, such as cerebrospinal fluid leakage or massive blood loss, and decide which type of TPS to use to ensure the successful completion of spinal fusion [16].

According to numerous researchers, including E. Adindu et al., patients diagnosed with metabolic syndrome tend to undergo longer surgical procedures, have extended hospital stays, and exhibit increased rates of postoperative complications such as dura mater tears, infections, and re-operations [17].

Recent innovations in lumbar spine surgery have enhanced technical accuracy and perioperative efficiency without compromising patient safety [18, 19]. A meta-analysis by G. Galieri et al. showed that intraoperative navigation improved tool precision, while augmented reality (AR) improved the ergonomics of the procedure [20].

The 2D/3D registration methodology with augmented reality visualization effectively addresses key limitations of current navigation paradigms, maintaining high accuracy standards during surgery. Augmented reality navigation with two- and three-dimensional registration is a promising technological advancement that can increase the accuracy and effectiveness of spinal instrumentation procedures [21].

Conclusions

The developed algorithmic scheme allows for a structured assessment of complication risks, planning surgical treatment based on modern technologies and knowledge, and ensuring control over all critical points, with an individualized approach to each patient. The integration of spinal navigation and neuromonitoring into the surgical process will help minimize complications during transpedicular fixation in patients with spinal diseases.

The practical use of the methods developed in this study for reducing postoperative inflammatory complications following transpedicular implantations, particularly through the registration of preoperative clinical-laboratory and biochemical deviations from normal values, may prevent complications, resulting in reduced patient severity, shorter hospital stays, and most importantly, improved treatment outcomes.

Conflict of Interest. The authors declare no conflicts of interest.

Prospects for Further Research. The authors plan to continue work in the direction of developing and implementing therapeutic and organizational measures to reduce complications in transpedicular fixation during the treatment of degenerative diseases and deformities of the thoracic and lumbar spine. Spe-

cifically, the current conceptual work needs to be confirmed under clinical conditions.

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Author Contributions. Bondarenko S. E. — Justified the relevance of the study and developed its concept; Barkov O. O. — Analyzed literature sources and the results of own surgical interventions; Tulyakov V. O. — Conducted research on scientific and medical information and participated in the development of the main sections of the article.

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RECOMMENDATIONS FOR PREVENTING POSTOPERATIVE COMPLICATIONS OF TRANSPEDICULAR SCREW FIXATION IN PATIENTS WITH SPINAL DISORDERS

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