ISSN 2663-9084 (Print)
ISSN 2663-9092 (Online)

Ukrainian Neurosurgical Journal

Vol. 31, N2, 2025

Is a scholarly Open Access journal
Founded in April 1995. Quarterly.
State Registration Certificate KV No 23771-13611PR dated 14 February 2019

The journal is on the List of Scientific Professional Editions of Ukraine, where results of thesis research for earning academic degrees of doctor and candidate of sciences and PhD may be published (Order of the Ministry of Education and Science of Ukraine No. 1721 dated 10 December 2024)
The journal is included in the Scopus scientometric database.

Journal publishes peer-reviewed works.

Founders

Romodanov Neurosurgery Institute

Ukrainian Association of Neurosurgeons

National Academy of Medical Sciences of Ukraine

Publisher

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http://theunj.org

The journal went to press 05 June 2025

Format 60 × 841/8. Offset Paper No.1

Order No. 25-12

Circulation 300 copies

Polygraphic services

FOP Golosuy IE

Certificate AA No. 9221702

86 Kyrylivska st., Kyiv, 04080, Ukraine

Tel. +380 44 239-19-85

The master layout of the journal was approved and recommended for publication and distribution via the Internet at the joint meeting of the Editorial Board of the Ukrainian Neurosurgical Journal and the Academic Council of Romodanov Neurosurgery Institute (Meeting Minutes N. 8 dated 23 May 2025)

On the cover

Figures from the article by Oleksandr M. Molodetskyi "Diagnosis and endoscopic treatment of suprasellar arachnoid cysts in pediatric patients: A case series and analysis of clinical observations", p. 86-92

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Review article

Ukrainian Neurosurgical Journal. 2025;31(2):3-9
doi: 10.25305/unj.326236

Application of endovascular embolization of the middle meningeal artery in the treatment of chronic subdural hematomas: A literature review

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Received: 05 April 2025
Accepted: 07 May 2025

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Introduction. Interest in this research topic arises from the fact that chronic subdural hematoma (CSDH) is currently one of the most common neurosurgical diagnoses in adults. Over the past decade, the incidence of CSDH has more than doubled. Recent studies have significantly enhanced our understanding of the mechanisms underlying the formation of CSDH, linking it to recurrent microbleeds in the subdural space from fragile, newly formed vessels within the hematoma capsule. Most of these vessels originate from the distal branches of the middle meningeal artery (MMA). Accordingly, endovascular embolization of the MMA may help eliminate chronic recurrent bleeding into the subdural space and facilitate hematoma resorption.

Objective of the study. To summarize current concepts regarding the pathophysiology of CSDHs and analyze the implementation and use of endovascular embolization of the MMA in contemporary treatment strategies for CSDH based on literature data.

Results. A detailed analysis of the literature indicates that a new understanding of the primary pathological process of CSDH has substantiated approaches to diagnosing and treating this pathology as an angiogenic process. Recent research findings demonstrate that endovascular embolization of the MMA in patients with CSDH is a safe and effective method to prevent recurrence or progression of subdural hematomas. Comparing different classes of embolic materials in the treatment of patients with CSDH represents the next step in ongoing research aimed at standardizing the overall treatment protocol for chronic subdural hematoma.

Keywords*: chronic subdural hematoma, middle meningeal artery, endovascular embolization.*

Relevance

Chronic subdural hematoma (CSDH) is currently one of the most common neurosurgical diagnoses in adults. Its prevalence is significantly higher among the elderly, with the average age at diagnosis being approximately 70–80 years (The data presented are the results of studies conducted in the USA and European countries). The estimated incidence of the condition ranges from 1.7 to 20.6 cases per 100,000 people per year. Over the past few years, the overall incidence of CSDH has more than doubled, and this trend is expected to continue.

In today's world, most countries are experiencing an increase in the elderly population, a wider use of various antiplatelet and anticoagulant medications, and continuous advancements in the accessibility and quality of neuroimaging technologies. These factors collectively explain the current statistical trends in the incidence of CSDH [1, 2].

Unlike acute subdural hematoma, which directly causes acute compression of the adjacent brain areas, CSDH is associated with recurrent microbleeds into the subdural space from fragile newly formed vessels within the hematoma capsule. These vessels predominantly originate from the distal branches of the MMA. Accordingly, endovascular embolization of the MMA can help eliminate chronic recurrent bleeding into the subdural space and facilitate the resorption process of the hematoma [3].

This review aims to summarize current concepts of the pathophysiology of CSDHs and to examine the implementation of MMA endovascular embolization in modern treatment strategies for CSDHs based on data from the literature.

Introduction

Historically, the formation of CSDH was considered a consequence of bleeding primarily from ruptured bridging veins due to traumatic brain injury. However, contemporary understanding of the primary pathological process in CSDH points to the development of neovascularized hematoma capsules [3]. These capsules are a hallmark feature of CSDHs. Recent studies have explored the pathophysiology of CSDH in detail using cerebral angiography and histopathological methods, substantiating the view of CSDH as an angiogenic pathological process. The capsules of CSDHs are characterized by the presence of newly

formed thin-walled capillaries lacking a smooth muscle layer and containing numerous interendothelial gap junctions, which facilitate continuous exudation. Thus, the immature and fragile capillaries within the capsule, prone to rupture, sustain the existence and progression of CSDH [4, 5]. The vascular supply to CSDH capsules predominantly originates from the external carotid artery via the MMA. Due to continuous microbleeds caused by the increased permeability of these capsules, the subdural space becomes filled with fluid [6]. The findings of recent studies have significantly expanded the previous understanding of the mechanism underlying CSDH, which was previously attributed solely to the rupture of bridging veins due to trauma. These advancements have enabled the development of diagnostic and treatment approaches that address CSDH as a complex angiogenic pathology.

Recent studies on the **pathophysiological mechanisms** underlying CSDHs have focused on several critical processes implicated in their progression, including angiogenesis, fibrinolysis, and inflammation. The membrane of a CSDH is considered a primary source of both fluid exudation and recurrent microhemorrhages. Angiogenic stimuli contribute to the formation of fragile neovasculature within the hematoma membrane, making it susceptible to repeated bleeding. Concurrently, enhanced fibrinolytic activity prevents stable thrombus formation, thereby facilitating persistent hemorrhagic events. Furthermore, both the hematoma membrane and its fluid content are characterized by a significant presence of inflammatory cells and mediators, which are believed to promote sustained membrane proliferation and hematoma expansion.

A comprehensive understanding of the pathophysiological processes involved in CSDHs formation has been instrumental in guiding the development and rationale of therapeutic strategies for affected patients. Numerous studies have demonstrated that key mediators involved in neovascularization and angiogenesis are present in individuals with CSDHs. Among these, angiopoietins represent a class of growth factors that play a pivotal role in regulating angiogenesis and vascular permeability. The overexpression of angiopoietins may serve as a driving force behind the formation of fragile neovessels within the membranes of chronic subdural hematomas. Moreover, the fluid within CSDHs contains vascular endothelial growth factor (VEGF) at significantly higher concentrations than those observed in peripheral blood and cerebrospinal fluid. VEGF is a potent pro-angiogenic factor known to enhance microvascular permeability.

Recent investigations suggest that multiple interrelated factors contribute to the initiation and progression of CSDHs. Following traumatic brain injury, a complex cascade of events—including hematoma membrane formation, angiogenesis, and fibrinolysis—appears to underlie the gradual enlargement of the hematoma. The vascularized and highly permeable membrane of a chronic subdural hematoma serves as a continuous source of inflammatory mediators and recurrent bleeding. These insights into the underlying pathophysiological mechanisms have paved the way for therapeutic approaches that aim not only to manage the hematoma but also to target its root causes [3, 4, 5].

Clinical diagnosis of CSDH can be challenging, as the disease often progresses without clear or specific symptoms in its early stages. Although the duration of the process is frequently unknown at the time of initial diagnosis, it is believed that CSDH develops over a period of three weeks or more. CSDHs manifest with a wide range of symptoms, from acute plegia to mild cognitive impairment.

The majority of patients with CSDH are elderly, and other age-related conditions, such as strokes, Alzheimer's disease, Parkinson's disease, dementia, and others, can clinically mask this condition. Patients with CSDH often present with complaints of behavioral changes or cognitive decline. In older individuals, these changes are sometimes mistakenly attributed to dementia, particularly if such a diagnosis has been made previously. (CSDH is considered one of the common causes of reversible dementia.)

For this reason, CSDH has earned the nickname "the great imitator," and a significant number of cases are diagnosed at late stages [7, 8].

Various approaches to the treatment of CSDH are actively discussed in the scientific literature. Conservative treatment is generally reserved for patients without neurological deficits when the maximum thickness of the hematoma is less than 10 mm and the midline shift does not exceed 5 mm. For patients with more pronounced symptoms or larger CSDHs, surgical treatment is typically preferred.

Although surgical treatment is considered the mainstay in the management strategy for patients with symptomatic CSDHs, several recent studies have focused on pharmacological treatment in such cases. The use of modern pharmacological approaches is based on a thorough understanding of the pathophysiology of CSDHs. Agents including corticosteroids, tranexamic acid, statins, and angiotensin-converting enzyme inhibitors are employed either as monotherapy or as adjuncts to surgical intervention. According to numerous studies, the rationale for prescribing corticosteroids in the treatment of patients with CSDHs is supported by their well-established anti-inflammatory, antifibrinolytic, and antiangiogenic properties.

The effectiveness of corticosteroid therapy has been evaluated based on the regression of neurological symptoms and the resorption of subdural hematoma as assessed by cranial computed tomography CT (Key radiological indicators included a reduction in hematoma thickness, midline shift, and hematoma density). Thus, corticosteroids may play a significant role as part of the treatment plan for patients with chronic subdural hematomas.

Tranexamic acid is a well-known antifibrinolytic agent that acts by competitively inhibiting plasminogen activation and plasmin activity. Activation of the kallikrein system by plasmin-mediated inflammatory triggers leads to increased vascular permeability and leukocyte migration (processes that have been identified in the capsule of chronic subdural hematomas). Recent studies aim to confirm the hypothesis that tranexamic acid may suppress the hyperfibrinolytic activity and increased vascular permeability of the hematoma capsule, thereby promoting gradual hematoma absorption. Researchers have demonstrated that the use of tranexamic acid

effectively contributes to hematoma volume reduction and lowers the risk of recurrence.

In most proposed treatment protocols for CSDHs, a statin—most commonly atorvastatin—is used. Atorvastatin acts as a competitive inhibitor of 3-hydroxy-3-methylglutaryl-coenzyme A reductase, thereby enhancing clearance and reducing circulating levels of low-density lipoproteins. Studies show that including atorvastatin in the comprehensive treatment of chronic subdural hematomas significantly improves long-term clinical outcomes.

Although pharmacological treatment is not generally considered an alternative to surgery—which remains the gold standard in the management of CSDH—the use of various pharmacological agents has been associated with improved surgical outcomes. Pharmacological treatment alone is typically deemed appropriate for elderly patients or those with contraindications to surgical intervention [9, 10, 11].

One of the primary challenges of surgical removal of CSDHs is the tendency for hematomas to recur, often accompanied by worsening neurological status and requiring repeat surgical intervention. The recurrence rate reported in different studies varies significantly, ranging from 5% to 37%, with most estimates falling between 10% and 20%. The need for repeat surgeries is reported to be as high as 12%. [9, 10, 11]. Another significant issue with surgical intervention is that most patients with CSDH are elderly individuals with multiple comorbidities, which increase the risk of transcranial surgical procedures. This explains the attractiveness of exploring less invasive treatment options for CSDH. In this context, MMA embolization has been proposed as a promising alternative and/or supplement to transcranial surgical interventions.

A recent meta-analysis by Chen H. et al. demonstrated that the use of endovascular embolization of the MMA in the treatment of CSDH reduces the rate of repeat surgical interventions to 4.6%-6.8% [12].

The results of three randomized, prospective studies on endovascular embolization of the MMA for the treatment of CSDH were presented at the International Stroke Conference 2024 in Phoenix, USA. The study titled "Middle Meningeal Artery Embolization Using Onyx Liquid Embolic System in the Treatment of Subacute and Chronic Subdural Hematoma" (EMBOLISE) NCT04402632 is a multinational, prospective, randomized, controlled, open-label, adaptive clinical trial initiated by researchers to evaluate endovascular embolization for patients with symptomatic CSDH. The study is being conducted at 39 centers across the USA using Onyx (Medtronic Neurovascular, Irvine, CA) with a target enrollment of up to 600 patients, divided into two groups.

The first group consists of patients with mild manifestations of CSDH, specifically with a midline shift <5 mm, hematoma thickness ≤15 mm, and mild neurological symptoms. Patients in this group were randomly assigned into two subgroups (1:1). One group received only conservative treatment for CSDH, while the other subgroup was treated with endovascular embolization of the MMA.

The second group of the study included patients with moderate or severe manifestations of CSDH: those with significant neurological deficits, midline shift ≥5 mm, and/or hematoma thickness >15 mm. This group was also randomly divided into two subgroups (1:1). One subgroup underwent surgical removal of the CSDH, while the other subgroup received surgical removal combined with endovascular embolization of the MMA.

The primary objective of the study was to determine the recurrence rate of CSDH requiring repeat surgical intervention within 90 days. Additionally, the study assessed the completeness of MMA embolization, changes in functional status of patients according to the modified Rankin Scale (mRS), and neuroimaging results after 90 days.

According to the published data from the EMBOLISE study, the recurrence rate of CSDH requiring repeat surgical intervention was significantly lower in the subgroup of patients treated with additional endovascular embolization (4.1% vs. 11.3%) compared to the subgroup receiving only surgical removal (95% CI 0.11–0.80, P=0.0081). Furthermore, in the subgroup receiving surgical removal with MMA embolization, the rate of neurological deterioration (mRS) (11.9% vs. 9.8%; P=0.0022) and the rate of serious complications or death within 90 days did not differ significantly from the control group. (National Institutes of Health. Embolization of the middle meningeal artery with ONYX ™ liquid embolic system for subacute and chronic subdural hematoma(EMBOLISE).2020. https://ClinicalTrials.gov/show/NCT04402632).

A clinical study on MMA embolization for CSDH is also ongoing: Managing Non-Acute Subdural Hematoma Using Liquid Materials: A Chinese Randomized Trial of Middle Meningeal Artery Treatment (MAGIC-MT), a multicenter, prospective, randomized clinical trial involving 722 patients at 31 centers in China. According to the published protocol, the MAGIC-MT study compares the treatment outcomes of two groups of patients with CSDH (randomization 1:1).

In the first group, patients underwent embolization using Onyx for the MMA before CSDH drainage, while the second group received conservative treatment. Treatment outcomes were compared by the recurrence or progression of CSDH requiring surgical intervention within 90 days.

Patients who received endovascular MMA embolization for the treatment of CSDH had a significantly lower risk of repeat surgical interventions compared to the control group—7.2% vs. 12.2% (95% CI 0.37 - 0.63, P=0.02). Additionally, this group of patients experienced significantly fewer complications within 90 days—6.7% vs. 11.6% (95% CI 0.32 - 0.92, P=0.02) [13].

Another study, Squid Trial for the Embolization of the MMA for the Treatment of CSDH (STEM), is a prospective, randomized clinical trial conducted at 33 centers in the USA, France, and Spain, involving 310 patients with CSDH. In the STEM study, patients with CSDH were randomized into two groups (1:1): a standard treatment group and a group treated with MMA embolization using Squid (Balt, Montmorency, France).

The treatment outcomes were compared based on the recurrence rate of CSDH that required repeat surgical removal of the hematomas within 180 days. (National Institutes of Health. The SQUID trial for the embolization of the MMA for the treatment of CSDH (STEM). 2020. https: // ClinicalTrials.gov /show / NCT04410146).

The STEM study, like EMBOLISE and MAGIC-MT, showed that treatment of CSDH with endovascular embolization was more effective than treatment without this technique in preventing recurrence or progression of CSDH (15.2% vs. 39.2%; 95% CI 1.91–6.78, P=0.0001).

The results of all three studies suggest that MMA embolization in the treatment of CSDH is a safe and effective method for preventing recurrence/progression of CSDH, especially as an adjunct to surgical treatment. MMA embolization has been proposed as a potential option for the standard treatment protocol for CSDH. This represents a significant positive breakthrough in the treatment of CSDH in recent years [14].

Currently, additional studies are planned, specifically focusing on the role of endovascular embolization of the MMA as a standalone treatment method for CSDH, as well as its effectiveness in patients with bilateral subdural hematomas. Ongoing randomized, multi-center studies investigate these aspects, along with the effectiveness of different embolization agents. These studies aim to further clarify the potential of MMA embolization in various clinical scenarios and contribute to optimizing treatment protocols for CSDH [15, 16].

Ebolic Agents: As endovascular embolization of the MMA is actively being studied as a treatment option for CSDH, significant attention in recent research has been given to studying embolic materials. In modern clinical practice, the aforementioned embolic agents are used in the treatment of cerebral arteriovenous malformations, dural arteriovenous fistulas, and other cerebrovascular pathologies requiring vascular occlusion.

The extensive experience gained over recent decades with various classes of embolic agents enables the selection of the optimal approach to the procedure based on the clinical context.

Polyvinyl Alcohol (PVA) (Boston Scientific, Natick, MA, USA) and **Embosphere** (Merit Medical, USA) Embosphere Microspheres are biocompatible, hydrophilic, nonresorbable, microspheres produced from an acrylic polymer and impregnated with porcine gelatin. The mechanism of action of these agents involves adhesion to the vessel walls, which induces a chronic inflammatory response leading to vessel occlusion. However, the occlusion may be temporary due to the possibility of recanalization. Currently, PVA particles are the most commonly used embolic agents in studies examining endovascular embolization of the MMA in patients with CSDH. Both non-calibrated (non-spherical) PVA particles and calibrated (spherical) PVA microspheres are used.

PVA microspheres represent an innovative approach to embolization, offering increased accuracy and reducing the risk of complications associated with unpredictable reflux or particle aggregation. This advancement allows for more controlled and effective treatment outcomes in patients undergoing MMA embolization for CSDH. [17, 18]. In the study by Schwarz et al., PVA particles sized 250–350 micrometers were used for MMA embolization in patients with CSDH. This particle size range is often selected to balance effective occlusion of the targeted vessels while minimizing the risk of non-target embolization and other potential complications [19]. Kim et al. performed MMA embolization in patients with unsatisfactory evacuation of, particularly those who were on antithrombotic medications. This group of patients presents a unique challenge, as antithrombotic drugs can increase the risk of recurrence or complications due to ongoing bleeding or incomplete resolution of the hematoma after surgery. By using embolization, Kim et al. aimed to address these challenges by reducing the recurrence rate of CSDH and improving clinical outcomes in patients who might be at higher risk due to anticoagulant or antiplatelet therapy [20]. Ban et al. were the first to evaluate PVA particle embolization (150–250 μm) of the MMA as a primary treatment for CSDH in a cohort of 72 patients. In their study, all asymptomatic patients with subdural hematomas thicker than 10 mm demonstrated spontaneous resorption of the hematoma following the embolization procedure. This finding suggests that embolization of the MMA using PVA particles could be an effective approach for treating certain cases of CSDH, especially in asymptomatic patients, leading to a reduction in the need for surgical evacuation [21]. In the study by Onyinzo et al., all patients who underwent endovascular embolization of the MMA showed complete hematoma resorption, including those receiving antithrombotic medications. This result is particularly significant, as antithrombotic therapy is often associated with an increased risk of hematoma recurrence or complications. The success of embolization in these patients suggests that endovascular treatment can effectively manage CSDH, even in high-risk groups, by preventing further bleeding and promoting the complete resolution of the hematoma [22].

The results of studies demonstrate that endovascular embolization of the MMA using PVA particles is an effective method both for preventing recurrences and as a primary treatment for CSDH, particularly in patients with high surgical risk. This approach offers a less invasive alternative to traditional surgical methods, reducing the likelihood of reoperation and improving outcomes, especially for elderly patients or those with comorbidities that increase the risks associated with surgery.

Several recent studies have described the use of Embosphere 300–500 μm (Merit Medical) in the treatment of patients with CSDH. Tiwari et al. used Embosphere as the sole method for treating primary and recurrent CSDH, without surgical removal of the hematoma. The authors noted that the volume of the hematoma significantly reduced after embolization, regardless of the initial size. Follow-up examination at 6 months showed no recurrences. This suggests that Embosphere can be an effective and reliable option for managing CSDH, particularly in cases where surgery is not preferred or feasible [23]. Gomez-Paz et al. studied the resorption time of hematomas after embolization using Embosphere and EmboGold microspheres, which are impregnated with 2% elemental gold for visibility (Merit Medical, USA). Their findings suggest that Embosphere is a promising material for endovascular embolization of the MMA in the treatment of CSDH. It demonstrates high effectiveness and safety, particularly in patients at risk of recurrence or in cases of primary treatment. This highlights Embosphere as a valuable option in managing CSDH, offering a potential alternative to more invasive treatments [24].

Liquid embolic materials represent a broad class of agents that differ in chemical composition and mechanisms of action. They are unified by a physical property that aids in preventing unintended embolization and enhances imaging visibility. Owing to their ease of handling and the ability to achieve controlled delivery, liquid embolic agents have proven to be highly effective for MMA embolization. This category encompasses polymeric blends and sclerosing agents. Polymeric adhesive compounds undergo rapid polymerization upon contact with ionic components of blood, resulting in the formation of intravascular emboli. NBCA (n-Butyl Cyanoacrylate) (TruFill, USA) is a monomeric cyanoacrylate compound that promptly polymerizes into a solid matrix when exposed to blood plasma ions. Copolymers such as Onyx (Medtronic, USA) and Squid (Balt, France) precipitate within the vasculature, forming a cohesive, sponge-like embolic mass. Sclerosing agents induce endothelial injury and protein denaturation, leading to vascular sclerosis. Compared to particulate embolic agents, liquid embolics offer superior radiographic visualization and a reduced risk of non-target embolization. [25, 26].

NBCA (n-Butyl Cyanoacrylate) (TruFill, USA) is a monomeric cyanoacrylate adhesive that polymerizes into a solid mass upon contact with blood plasma ions. It also reacts with endothelial cells, catalyzing the formation of emboli. Lipiodol acts as a solvent for NBCA, allowing for adjustment of the concentration to regulate the polymerization speed of the mixture. This enables control over the flow rate and depth of penetration during embolization. It is precisely these properties of NBCA that enable controlled endovascular embolization, which, according to most researchers, is considered an advantage of this agent over other embolic materials. Additionally, Lipiodol improves the visualization of the embolizing material during and after the procedure. Ishihara H. et al. were among the first to use NBCA as the primary embolic agent for endovascular embolization of the MMA in the treatment of CSDH in patients with at least two recurrences. For embolizing the frontal and parietal branches of the MMA, the researchers used a solution of NBCA and Lipiodol in a 1:6 ratio. After 21 days, neuroimaging showed a reduction in the volume of the subdural hematoma by more than 75% in all patients. During the 15-month follow-up after the procedure, no recurrences were observed, and all patients showed a decrease in the size of the CSDH. [27, 28].

Onyx (Medtronic, USA) is a liquid embolic agent composed of an ethylene-vinyl alcohol copolymer solution and dimethyl sulfoxide. In contrast to cyanoacrylate-based adhesive compositions (NBCA), Onyx is a non-adhesive material, which reduces the risk of microcatheter occlusion. Waqas et al. conducted one of the first studies on MMA embolization for the treatment of CSDH using Onyx. In their study, all patients showed positive outcomes: complete resorption of the hematoma or a reduction in its size by more than 50% (according to neuroimaging methods) at the 2-month follow-up. Additionally, all patients experienced a full regression of neurological symptoms [29]. Another study involving 46 patients with CSDH treated with MMA embolization using Onyx-18 provided further evidence of the efficacy of this embolic agent. After 2 months, 86.4% of patients showed partial or complete resorption of the hematoma. Most of these patients underwent endovascular embolization of the MMA as the primary treatment method without the need for additional surgical hematoma removal. This reinforces Onyx-18's effectiveness as a stand-alone treatment option for CSDH, particularly in patients who are not candidates for or prefer to avoid surgery [30].

Squid (Balt, Montmorency, France) is a liquid embolic agent that contains a copolymer of ethylene-vinyl alcohol, micronized tantalum powder, and dimethyl sulfoxide. Similar to Onyx, Squid is used for endovascular embolization, but it features smaller particles of tantalum powder, which may enhance visualization compared to Onyx. A pilot study conducted by an international group of researchers involved patients who underwent MMA embolization with Squid 12 or Squid 18 after unsuccessful surgical removal of CSDH. The study found no thromboembolic or hemorrhagic complications, and all patients showed partial reduction of the CSDH (more than 50%) within 3 months following the embolization. This suggests Squid as a promising alternative for patients who do not respond well to surgery [31]. Currently, randomized controlled trials are ongoing to assess the efficacy and safety of new embolic agents, such as Squid and PHIL (MicroVention, USA), for the treatment of CSDH. Although these agents have not yet received FDA approval for the treatment of CSDH, they have already shown promising results in treating cerebral arteriovenous malformations (AVMs).

Squid and PHIL are copolymers that have different mechanisms of action compared to traditional agents like PVA or NBCA. They offer advantages in terms of controlled delivery and visualization, which is important for precise placement of the embolic material. However, since both materials have not been officially approved for CSDH treatment, further research is needed to compare their efficacy and safety with other embolization methods. Studies that involve comparing different embolic agents with varying mechanisms of action are likely to help determine the optimal treatment regimen for CSDH.

Conclusions

It is predicted that the incidence of CSDHs will continue to rise in the coming years. Therefore, the results of studies on treatment strategies for CSDH are becoming increasingly important.

According to current scientific sources, a new understanding of the pathogenesis of CSDH has emerged, linking the development of CSDH with angiogenic processes in the hematoma capsule, which explain the mechanisms underlying the transition and transformation of an acute subdural hematoma into a chronic subdural hematoma.These processes contribute to the persistence of recurrent microbleeds from fragile newly-formed blood vessels in the capsule into the subdural space, with most of these vessels originating from the distal branches of the MMA. This justifies the use of endovascular embolization of the MMA in the treatment of patients with CSDH.

The published results of randomized studies to date provide, for the first time, a sufficient level of evidence (level II) for clinical practice regarding the use of liquid

embolic agents in the endovascular embolization of the MMA for the treatment of CSDH in patients.

These studies demonstrate that endovascular embolization of the MMA should be considered a safe and effective treatment option and represents a significant breakthrough in the management of CSDH.

Currently, studies are planned and ongoing that compare different classes of embolizing materials to evaluate their relative efficacy and safety in the treatment of CSDH, as well as to determine their role in the overall treatment strategy for CSDH.

Disclosure

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This study received no financial support or sponsorship.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):10-27
doi: 10.25305/unj.320680

Evaluation of the efficacy of combined vitamin D_3 and K_2 therapy in reducing implant-associated complication risk and improving spinal fusion stability

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Received: 12 January 2025
Accepted: 28 February 2025

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In the last decade, the use of implants in spinal surgery has significantly increased, particularly interbody devices and transpedicular fixators. This trend has necessitated refining approaches aimed at preventing intra- and postoperative complications. A key factor influencing the effectiveness of stabilization procedures is bone mineral density (BMD).

Objective: To investigate the relationship among vitamin D levels, BMD, and the incidence of implant-related failures in patients who have undergone stabilization procedures on the spine, as well as to evaluate the role of postoperative correction of vitamin D_3 and K_2 deficiencies in enhancing fixation stability and reducing complication risks.

Materials and Methods: A retrospective single-center cohort study was conducted in specialized departments of Romodanov Neurosurgery Institute NAMS of Ukraine, from January 2023 to December 2024. A total of 250 patients who underwent spinal surgery with the use of transpedicular screws and/or interbody implants were analyzed with respect to their age, sex, body mass index, serum vitamin D (25-(OH)D_3) levels, and BMD (according to computed tomography data). Original grading scales were used to evaluate implant-related complications. Postoperative correction of vitamin D deficiency was carried out using "Solemax®" (vitamin D_3, vitamin K_2, and ω-3 polyunsaturated fatty acids).

Results: A high prevalence of vitamin D deficiency and reduced BMD was recorded among patients undergoing elective stabilization surgeries on the spine. A significant correlation was detected between 25-(OH)D_3 levels and bone tissue status. After 4 months of "Solemax®" administration, all patients achieved reference 25-(OH)D3 levels, indicating the effectiveness of the therapy. In the correction group, an increase in BMD was observed, whereas in the comparison group, BMD values decreased. The incidence of implant-related complications was statistically reduced: the risk of screw loosening decreased by 69.84% over the first 6 months and by 85.06% over one year, while the risk of interbody implant migration declined by 56.2% and 64.7%, respectively.

Conclusions: The stability of spinal fusion is more contingent upon the adaptive response of bone tissue to implantation than on absolute BMD values. The use of a balanced combination of vitamins D_3 and K_2 contributes to enhanced fixation stability and a lower risk of postoperative complications.

Keywords: *spine surgery; bone mineral density; vitamin D deficiency; implant-related complications; spinal fusion stability*

Introduction

Significant advances in scientific and technological progress, along with the implementation of highly effective treatment methods in practical healthcare, have considerably contributed to improving the quality and efficiency of medical care delivery to the population [1]. This trend is particularly evident in the field of surgery, which has seen both an expansion in the range of surgical procedures and an increase in their frequency. According to epidemiological studies, the global number of surgical interventions increased by more than 30% between 2000 and 2012 (from 226.4 to 312.9 million per year) [2]. However, it has also been reported that over 143 million necessary surgical procedures—vital for saving lives or preventing permanent disability—were not performed due to technical, economic, or other constraints [3].

A more pronounced dynamic is observed in spinal surgery, driven by demographic and technological factors as well as lifestyle-related aspects of certain population groups [4]. Technological advancements in spinal surgery over recent decades have significantly increased the use of implants, particularly interbody

constructs and transpedicular fixation devices. This trend reflects not only the refinement of surgical techniques but also the substantial broadening of indications for surgical intervention. In a study by S.S. Rajaee et al., which analyzed trends in spinal stabilization procedures in the United States from 1998 to 2008, a 137% increase in surgeries was noted (from 174,223 to 413,171 procedures, respectively) [5]. The greatest growth in surgical volume was observed among elderly patients, attributed to both the rising number of older individuals and the corresponding need to address degenerative spinal changes. The introduction of advanced fixation techniques has also contributed to the increase in surgeries. This was noted by M.-J. Reisener et al. [6], who reported a significant rise in the use of implants in lumbar spine surgeries. From 2002 to 2011, the number of lumbar spinal fusion procedures grew by 77% in the United States and by 63% in the United Kingdom. The authors cite the adoption of minimally invasive techniques and expanded surgical indications as key drivers of this growth.

An analysis of the publicly available U.S. National Inpatient Sample database revealed that national expenditures for thoracolumbar spinal stabilization procedures (excluding major complications or comorbidities) rose by $7.04 million (44.41%) from 2008 to 2014 [7]. This category of surgical intervention ranks first in economic significance among neurosurgical procedures—total costs exceeding those for craniotomies and endovascular cerebral procedures by a factor of 5.83—and ranks sixth in overall healthcare expenditures across Medicare Severity-Diagnosis Related Groups. According to the authors, this substantial increase is likely driven by a combination of factors, including enhanced understanding of spinal biomechanics, advancements in modern diagnostic techniques, improved surgical technologies and instrumentation, and an increase in average life expectancy.

It is natural that the active implementation of stabilization procedures in practical healthcare is accompanied by the evolution of methods aimed at preventing complications and adverse events, both those arising directly from the surgical intervention and those associated with its long-term outcomes. According to several studies, the application of intraoperative three-dimensional navigation (Image-Guided Navigation) allows for highly accurate placement of pedicle screws, achieving a Grade A rating under the Gertzbein–Robbins classification in up to 99% of cases [8]. This high precision is attributed to the ability to visualize patient anatomy in real time using three-dimensional imaging, thereby significantly reducing the likelihood of malpositioning [9, 10].

By contrast, the accuracy of pedicle screw placement when using traditional two-dimensional fluoroscopy ranges between 70–90%, which increases the risk of screw misplacement, fixation failure, and, in certain cases, damage to critical anatomical structures. Notably, the use of the conventional Free-hand technique results in incorrect transpedicular screw positioning in approximately one out of every six cases [11].

Furthermore, a range of complications unrelated to the surgical technique itself has been documented in spinal stabilization procedures. Quite often, failure to achieve secondary stable spondylosis, interbody implant dislocation, pedicle screw displacement or extraction, and the development of deformity of adjacent segments to the stabilized segments are frequently influenced by patient-specific factors, which complicates treatment strategies and underscores the need for a personalized approach to care [12]. A critical determinant of the success of spinal stabilization is bone mineral density (BMD) [13,14]. Various strategies have been developed to enhance the stability of spinal fixation, employing both localized and systemic methods. Almost the only method of etiotropic therapy of low BMD, vitamin D supplementation emerges as a foundational and broadly applicable intervention. It is favored for its affordability, ease of monitoring, and suitability for long-term outpatient administration. In cases of severe osteoporosis, vitamin D is often integrated into a comprehensive treatment regimen. When used in conjunction with calcium supplements, bisphosphonates, or anabolic agents such as teriparatide, vitamin D has demonstrated favorable clinical outcomes [15,16]. Given the endemic prevalence of vitamin D deficiency in Eastern European populations and its established influence on BMD, investigating the correlation between spinal fusion failure and vitamin D levels—as well as assessing the impact of postoperative vitamin D correction—represents an important area of research for improving the outcomes of spinal stabilization surgeries.

Objective: To investigate the relationship between vitamin D levels, bone mineral density (BMD), and the incidence of spinal fusion failure in patients undergoing spinal stabilization surgery, as well as to assess the role of postoperative correction of vitamin D_3 and K_2 deficiencies in enhancing fixation stability and reducing the risk of complications.

Materials and Methods

Study design

From January 2023 to December 2024, a retrospective monocentric cohort study was conducted at the specialized departments of the Romodanov Institute of Neurosurgery, National Academy of Medical Sciences of Ukraine.

Inclusion Criteria:

- Patients aged 18 to 81 years;
- Underwent stabilization surgery in the thoracolumbar spine using transpedicular screws and/or interbody implants;
- Availability of clinical documentation, including preoperative and postoperative follow-up data, enabling evaluation of fixation stability, implant positioning, and BMD;
- Postoperative dynamic assessment of 25(OH) D levels;
- Signed informed consent for data collection, processing, and publication of generalized results under the condition of confidentiality.

This article contains some figures that are displayed in color online but in black and white in the print edition.

Exclusion Criteria:

- Documented postoperative infectious-inflammatory complications at any time during the follow-up;
- BMD value <50 HU;
- Revision surgeries;
- Improper initial placement of implants (transpedicular screws or PLIF/TLIF cages);
- History of trauma and/or spinal surgery prior to the intervention analyzed in this study;
- Presence of neoplastic processes of any localization or any somatic pathology in the stage of decompensation;
- Persistent psychiatric or behavioral disorders.

Parameters studied:

Baseline clinical parameters included patients' age, sex, and body mass index (BMI).

Vitamin D (25-(OH)D) levels were classified as follows: normal – ≥30 ng/mL, insufficient – 20–29 ng/mL, deficient – <20 ng/mL [17]. If the results were reported in nmol/L, a conversion formula was applied: ng/mL = (nmol/L) ÷ 2.5

Bone mineral density was assessed using computed tomography (CT), which, according to several studies, provides more informative results for the spine than conventional dual-energy X-ray absorptiometry (DEXA) and is more accessible for neurosurgical patients, as it is often performed routinely [18]. Measurements were carried out using the RadiAnt DICOM Viewer software package (Medixant, Poland; version 2023.1, License No. 1860F047) at the level of the middle third of the L1 vertebral body. An ellipsoid region-of-interest (ROI) was drawn to include as much trabecular bone as possible while excluding the cortical shell. BMD values were classified as follows: normal – >120 HU, osteopenia – 80–120 HU, osteoporosis – 50–80 HU, severe osteoporosis – <50 HU [19–21]. Patients with BMD <50 HU were excluded from the study, as such cases typically require specialized surgical techniques (e.g., cannulated screws with polymethylmethacrylate augmentation) or nonsurgical approaches due to a very high risk of complications.

In some cases, preoperative preparation with therapy was conducted in specialized medical institutions.

Age groups for analysis were formed in accordance with the recommendations of the Endocrine Society Clinical Practice Guidelines and the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (ESCEO) [22].

Assessment of postoperative complications

Given the lack of a standardized classification in contemporary literature for fixation failure within the "pedicle screw–vertebral body" system—commonly referred to as "screw loosening"—we propose the following grading system based on existing studies [23–26]:

- Grade 0 (no loosening): The screw is visually and clinically stable, with no signs of osteolysis surrounding the screw as confirmed by CT or spondylography.
- Grade 1 (minimal loosening): Slight osteolytic changes around the screw (radiolucency <0.5 mm) observed on spiral CT (SCT); the screw shows slight instability, though clinical symptoms are absent or minimal. No changes are detectable on standard spondylography.
- Grade 2 (moderate loosening): Radiolucency of 0.6–2.0 mm around the screw; intraoperative palpation may reveal screw mobility. Clinically, this may present as mild pain or slight construct instability. Changes are not detectable via spondylography.
- Grade 3 (significant loosening): Radiolucency >2 mm; the screw is clearly unstable and may partially extrude from the bone structure. Clinical manifestations include pain, segmental instability, and functional impairment. Overloading of adjacent implant components may occur. These changes are verifiable on standard radiographs.
- Grade 4 (complete loosening): The screw completely loses fixation and may migrate. Associated with substantial bone defects, possibly resulting in secondary vertebral fracture. Clinically presents with acute pain, spinal instability, or neural compression.
- For the dislocation of interbody cages, we also propose the following classification based on descriptive studies [27–29], assessed via radiography or CT:
- Grade 0: No displacement.
- Grade 1: Mild displacement (<2 mm), with the posterior edge of the cage remaining within the vertebral body and without clinical symptoms.
- Grade 2: Moderate displacement (2–5 mm), with the posterior edge of the cage extending beyond the dorsal margin of the vertebral body, potentially compressing the intervertebral foramen or spinal canal; manifests as localized pain.
- Grade 3: Severe displacement (>5 mm), characterized by clinical signs of neural structure compression and necessitating surgical revision.

The initial evaluation of positioning was performed using standard spondylography. In case of verification ≥Grade 1, spiral computed tomography (SCT) was used for further monitoring. Postoperative vitamin D deficiency correction was administered using "Solemax® 4000" (Vitamin D_3 [cholecalciferol] – 100 mcg [4000 IU], Vitamin K_2 [menaquinone, MK-7] – 100 mcg, ω-3 polyunsaturated fatty acids – 400 mg) or Solemax® 5600 (Vitamin D_3 – 140 mcg [5600 IU], Vitamin K_2 – 100 mcg, ω-3 polyunsaturated fatty acids – 400 mg). Both formulations are manufactured by "Solepharm" LLC (Latvia). Serum 25-(OH)D_3 levels were monitored every two months until normalization was achieved, with follow-up measurements performed every six months thereafter. The frequency of follow-up X-rays or SCTs was determined based on clinical indications.

Statistical Analysis

Statistical analysis was conducted using R software (version 4.0.5, R Foundation for Statistical Computing) in the RStudio development environment (version 1.4.1106).

Results

A total of 250 clinical cases were included in the analysis based on the availability of medical records and postoperative follow-up data provided remotely by patients. Patients were categorized into three groups depending on their need for vitamin D_3 correction (based on 25-(OH)D_3 levels) and actual intake of "Solemax®":

1) No Need for Correction (NNC) – Patients whose vitamin D_3 levels were within the normal range and did not require correction.

2) Solemax® Recommended Dose (SRD) – Patients whose vitamin D_3 levels required correction and who received "Solemax®" at the recommended dosage.

3) Needed, but Not Treated (NNT) – Patients identified as needing correction of vitamin D_3 levels but who, for various reasons, declined any form of supplementation. This group was included in the analysis as they provided follow-up results of postoperative imaging (including spondylography) and laboratory data.

Vitamin D_3 correction in the postoperative period is not governed by any official protocols; thus, all prescriptions were of a recommendatory nature.

Primary data analysis revealed that patients in the NNC group were characterized by a statistically significantly younger age compared to those in the SRD and NNT groups. Additionally, the NNC group demonstrated significantly higher BMD values ($p < 0.001$) than the other groups. No cases of overt osteoporosis were identified, and osteopenia was observed in only 10.5% of cases.

The relatively younger age of patients in the NNC group also influenced the types of surgical interventions performed. Lumbar discectomies with posterior lumbar interbody fusion (PLIF) was the predominant procedure. Isolated transpedicular fixation (TPF) was primarily carried out using minimally invasive techniques in cases of uncomplicated traumatic spinal injuries that required indirect decompression and stabilization. The primary indications for combined PLIF and TPF were unstable spondylolisthesis with radiographic evidence of spondylolysis.

The SRD and NNT groups, whose data were used for further analysis, showed no statistically significant differences in the parameters studied, confirming their comparability and the validity of subsequent analysis. Statistical evaluation of the entire patient cohort enabled the identification of certain associations consistent with existing literature, supporting the robustness of the data collection and analysis methodology.

Of particular note is the observed correlation between BMD, patient age, and sex ***(Fig. 1A)***.

In individuals under the age of 40, predominantly normal bone mineral density (BMD) values were recorded. Among 88 patients in this age group, 63 (71.6%) had BMD values ≥120 HU, 20 (22.7%) had values in the range characteristic of osteopenia, and 5 (5.7%) had values corresponding to osteoporosis. The distribution of data demonstrated moderate variability,

Table 1. Brief characteristics of patient groups

Indicator	Group			P*
	NNC (n=38)	SRD (n=115)	NNT (n=97)	
Sex:				0,1378Δ
men	14 (36,84 %)	43 (37,39 %)	47 (48,45 %)	
women	24 (63,16 %)	72 (62,61 %)	50 (51,55 %)	
Age, years (median):	29 (95 % CI – 26,94–33,58)	51 (95 % CI – 46,98–51,84)	47 (95 % CI – 45,68–51,16)	0,3027#
18–40	32 (84,21 %)	28 (24,35 %)	33 (34,02 %)	0,2299*
41–60	5 (13,16 %)	62 (53,91 %)	42 (43,3) %	
>60	1 (2,63 %)	25 (21,74 %)	22 (22,68 %)	
Body mass index, kg/м2 (median)	24,55 (95 % CI – 22,77–25,01)	24,20 (95 % CI – 23,64–25,15)	25,40 (95 % CI – 24,51–26,13)	0,07307#
Type of surgical intervention:				0,3382*
PLIF	30 (78,95 %)	69 (60 %)	50 (51,55 %)	
TPF	2 (5,26 %)	14 (12,17 %)	18 (18,56 %)	
TPF + PLIF	6 (15,79 %)	32 (27,83 %)	29 (29,9 %)	
BMD, HU (median):	156,65 (95 % CI – 145,72–163,19)	93,90 (95 % CI – 94,11–104,42)	96,10 (95 % CI – 95,56–105,52)	0,4631#
normal	34 (89,47 %)	23 (20 %)	23 (23,71 %)	0,5972*
osteopenia	4 (10,53 %)	62 (53,91 %)	54 (55,67 %)	
osteoporosis	–	30 (26,09 %)	20 (20,62 %)	
25-(OH)D3, ng/ml:	43,53 (95 % CI – 41,21–48,94)	20,68 (95 % CI – 20,35–21,67)	20,09 (95 % CI – 20,42–21,97)	0,9919#
normal	38 (100 %)	–	–	0,4005Δ
insufficient	–	67 (58,26 %)	50 (51,55 %)	
deficient	–	48 (41,74 %)	47 (48,45 %)	

Notes:

PLIF – posterior lumbar interbody fusion; TPF – transpedicular fixation; BMD – bone mineral density; CI – confidence interval.

*Statistical significance of differences between the SRD and NNT groups was calculated; Δ – Pearson's χ^2 test with Yates' continuity correction; #– Wilcoxon rank-sum test with continuity correction; * – Pearson's χ^2 test.*

as indicated by the coefficient of variation (CV = 22.96%), suggesting relative stability in BMD values within this age group despite individual differences. The analysis revealed an almost linear inverse relationship between BMD and age, confirmed by Pearson's correlation coefficient (r = −0.684). Statistically significant sex differences in BMD were found in patients under 40: the median BMD was 149.40 HU (95% confidence interval [CI]: 137.14–154.15) in women and 130.50 HU (95% CI: 117.81–138.42) in men (p = 0.0044).

The 41–60 age group was characterized by a noticeable decline in BMD. In this group, 64.9% of patients had values consistent with osteopenia, 22.8% with osteoporosis, and only 12.3% had normal BMD values. The dispersion of values was also moderate (CV = 20.92%). In contrast to the younger cohort, an inverse trend in BMD relative to sex was observed: women had a median of 91.30 HU (95% CI: 87.14–97.41), while men had a median of 94.90 HU (95% CI: 92.00–102.91); however, the difference was not statistically significant (p = 0.1266). The correlation between bone tissue status and age was also considerably weaker compared to younger patients (r = −0.2614), indicating a diminished age-related dependency of BMD in this group. A visual analysis of the trend lines ***(see Fig. 1A)*** further supported that the age-BMD relationship in men was notably weaker than in women. This may reflect sex-specific dynamics in bone density, potentially associated with differences in metabolic and hormonal factors.

In patients over the age of 60, a similar trend was noted as in younger individuals. The proportion of patients with osteoporosis was 29.6%, with osteopenia—54.2%, and with normal BMD—6.3%. The median values for women and men were 80.30 HU (95% CI: 74.53–85.76) and 96.45 HU (95% CI: 84.75–103.94), respectively, with a statistically significant difference (p = 0.0125).

Based on existing literature, a substantial decrease in BMD in postmenopausal women could have been expected during analysis; however, when interpreting the results, it is important to consider that patients with pronounced manifestations of osteoporosis were not included in the study. The analysis of 25-(OH)D₃ levels by age group revealed a similar trend, albeit with specific nuances ***(Fig. 1B)***. In younger patients (<40 years), higher levels of 25-(OH)D₃ were expectedly recorded. Nevertheless, even within this age group, only 36.36% of patients had normal vitamin D₃ levels, while insufficiency and deficiency were observed in 44.32% and 19.32% of patients, respectively. In the 40–60-year-old age group, the distribution of 25-(OH)D₃ levels was 4.38%, 50.0%, and 45.61%, respectively, and among patients over 60 years of age—2.08%, 43.75%, and 54.17%.

The median 25-(OH)D₃ values across age groups were as follows:

- <40 years: 27.23 ng/mL (15.94–65.28); males—22.97 (95% CI: 24.32–32.62), females—29.32 (95% CI: 29.01–36.79);
- 40–60 years: 20.26 ng/mL (15.15–33.71); males—20.61 (95% CI: 20.34–23.84), females—19.70 (95% CI: 19.73–22.58);
- >60 years: 19.56 ng/mL (15.13–29.79); males—21.24 (95% CI: 18.21–26.86), females—19.38 (95% CI: 18.75–21.08).

The 25-(OH)D₃ levels were low even when accounting for the endemic nature of vitamin D deficiency in Ukraine. However, these findings reflect the status not of the healthy population but of patients with musculoskeletal disorders, particularly spinal conditions. The development and progression of such diseases may be driven by vitamin D deficiency, which has a considerable impact on bone health and metabolism. Conversely, the presence of musculoskeletal pathology that limits mobility likely contributes to reduced sun exposure, thereby impeding adequate cutaneous synthesis of vitamin D. This is further supported by the observation that the variability of 25-(OH)D₃ levels in the younger age group was significantly higher (CV = 43.1%) compared to older age groups (CV = 27.29% and 30.61% for the 40–60 and >60 age groups, respectively). This may indicate greater heterogeneity in the factors influencing vitamin D levels among younger patients, including lifestyle characteristics, dietary habits, and individual metabolic differences.

The correlation between serum 25-(OH)D_3 levels and bone mineral density (BMD) in patients with spinal pathology, as analyzed in our study, follows an approximately linear sigmoidal relationship with asymptotes defined as physiologically acceptable limits ***(Fig. 2)***. The variability in 25-(OH)D_3 levels decreases with increasing severity of osteoporotic changes (37.79% in individuals with normal BMD, 28.78% with osteopenia, and 11.3% with osteoporosis), which is likely underpinned by a pathophysiological basis.

The nature of the analyzed dependency allows for mathematical modeling using a modified Michaelis–Menten saturation function. In this case, a modification is employed to incorporate an asymptotic growth parameter, which corresponds to one of the variants of the four-parameter logistic function. This approach enables the mathematical characterization of nonlinear changes in system parameters by accounting for the baseline level, growth rate, and asymptote. The relationship is described by the following formula:

$$\mathrm{BMD} = a + \frac{(d-a)}{1+e^{-b\,(VitD3-c)}} \quad (1),$$

Where: BMD – radiologically measured bone mineral density, in Hounsfield units (HU);

$VitD_3$ – serum level of 25-hydroxycholecalciferol, in ng/mL;

a (lower asymptote) – baseline BMD level in cases of severe vitamin D deficiency;

d (upper asymptote) – threshold beyond which increasing vitamin D level has no significant effect;

b (slope) – rate of change in BMD relative to vitamin D level;

c (inflection point) – point at which vitamin D has the most effective impact on bone density.

The resulting predictive model produced the following parameter estimates:

$a = 78.76 \pm 6.18$ ($p < 0.001$), $d = 155.42 \pm 4.16$ ($p < 0.001$), $b = 0.324 \pm 0.077$ ($p < 0.001$), $c = 24.78 \pm 0.77$ ($p < 0.001$).

The mean prediction error was 21.88, indicating a high level of accuracy for modeling biological processes ***(Fig. 3)***.

The next stage of the analysis involved examining the effect of "Solemax®" on serum 25-(OH)D_3 levels. The dynamics of changes, stratified by age categories and taking into account gender, are presented in ***Fig. 4***.

According to initial testing, in the SRD group, 26.92% of patients under the age of 40 had a vitamin D deficiency (11.54% of men and 15.38% of women). A vitamin D insufficiency was recorded in 73.08% of patients (30.77% of men and 42.31% of women). After two months of taking "Solemax®", insufficiency persisted in only 3.85% of patients, while a normal 25-(OH)D_3 level was achieved in 96.15% of patients (42.31% of men and 53.85% of women).

In the 40–60 age group, vitamin D deficiency was detected in 48.44% of patients (14.06% of men and 34.38% of women), and insufficiency in 51.56% (20.31% of men and 31.25% of women). After two months of "Solemax®" administration, insufficiency persisted in 25.0% of patients (equally among men and women), and normalization of the indicator was achieved in 75.0% of patients (21.88% of men and 53.12% of women). Thus, the dynamics of the regression of serum 25-(OH)D_3 insufficiency were somewhat lower compared to younger patients.

Even less pronounced changes were recorded in the age group over 60 years. According to baseline testing, 40% of patients had a vitamin D deficiency (12% of men and 28% of women), while the rest showed insufficiency (28% of men and 32% of women). After two months of taking "Solemax®", insufficiency persisted in 32% of patients (12% of men and 20% of women), while a normal 25-(OH)D_3 level was achieved in 68% of patients (28% of men and 40% of women).

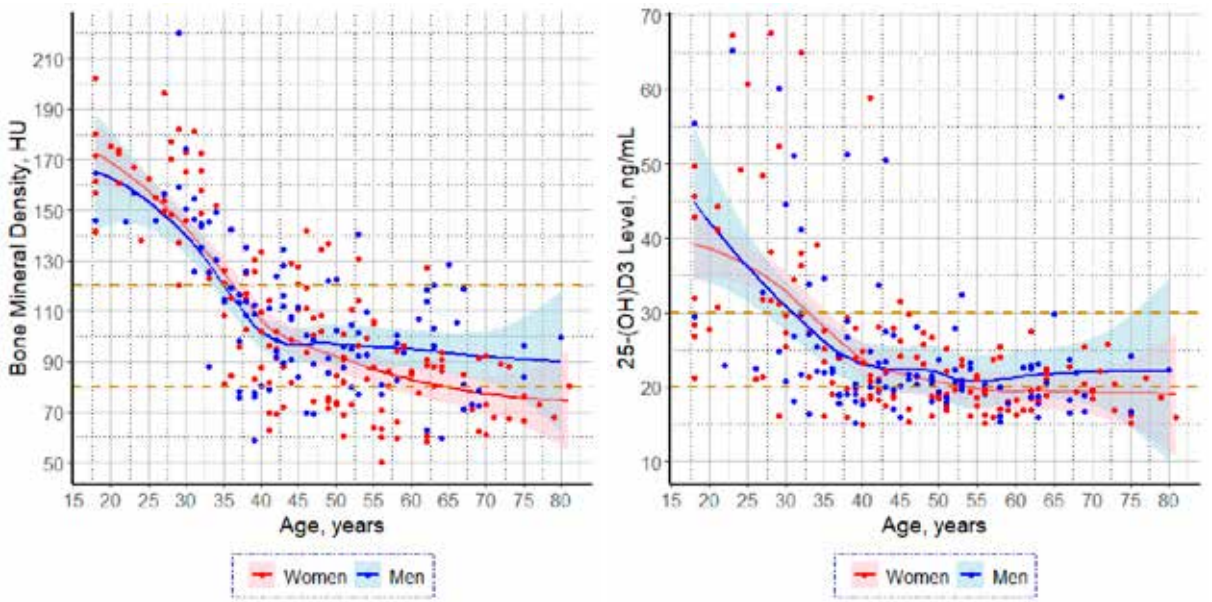

Fig. 1. Association of patient age with bone mineral density (A) and vitamin D3 level (B)

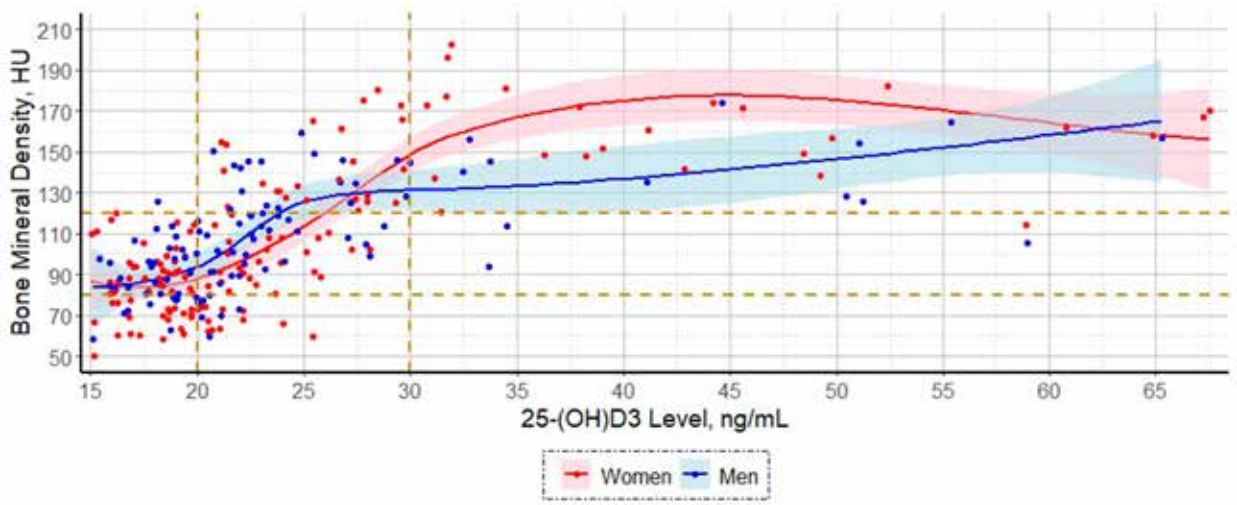

Fig. 2. Relationship between Vitamin D3 level and BMD

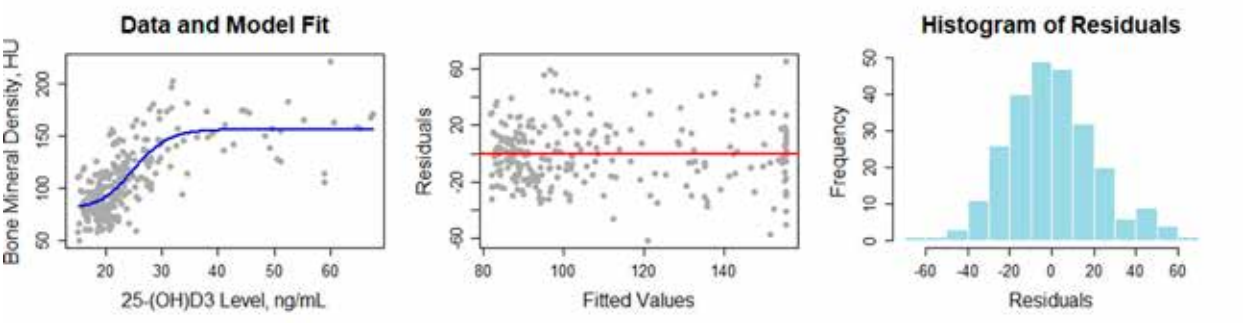

Fig. 3. Graphical evaluation of the model quality characterizing the relationship between vitamin D levels and BMD (explanation provided in the text)

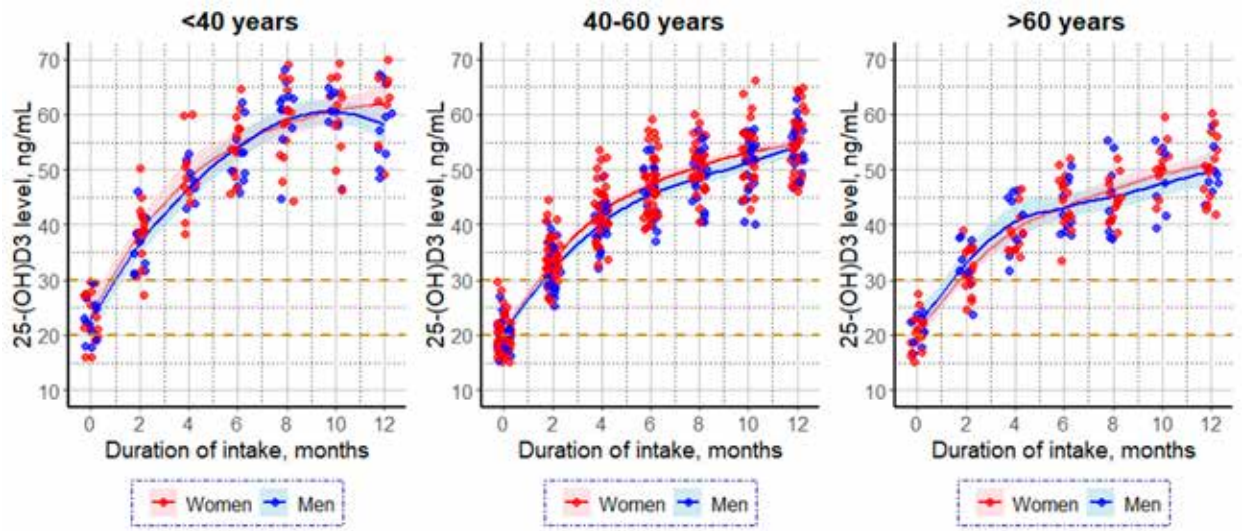

Fig. 4. Dynamics of 25-(OH)D3 levels in blood serum during "Solemax" intake in the postoperative period

After four months of "Solemax®" intake, 25-(OH)D3 serum levels were within the reference range in all SRD group patients.

Visual assessment of the graphs, as well as the nature of the process under investigation, allow for the approximation of the dynamics of serum 25-(OH)D3 levels using a logarithmic curve, enabling a mathematical analysis of the quantitative change in this indicator. The model

$$\Delta VitD3 = a + (b \cdot \ln(T)) \quad (2),$$

where – increment in vitamin D level;

T – time (in months, starting from T = 1, to avoid ln (0));

a – the initial increment level, which is a constant;

b – coefficient reflecting the intensity of change in vitamin D increment over time.

Modeling was performed for each age group and sex using equation (2). The analysis results enabled the identification of key patterns. Specifically, comparison of age groups revealed a gradual decrease in both the growth rate (*b*) and the initial growth level (*a*) with increasing age. In males, the initial level (*a*) was higher across all age groups, but it declined more sharply with age. In females, the growth rate (*b*) remained higher than in males across all age groups, indicating a more pronounced dynamic in changes of vitamin D_3 levels.

The slowdown points (T_{25}, T_{10}, T_{50}, T_{75}, T_{95}) remained stable across all age groups for both males and females. This suggests that the process of slowing vitamin D_3 level growth follows a similar pattern regardless of age, albeit with differences in speed and initial level between groups. ANOVA confirmed the significance of the models across all age groups separately for males and females, indicating differences in dynamics between the sexes. However, in older age groups, differences between the individual and the combined model became less significant, suggesting convergence of overall dynamics between males and females with age.

The identified relationships allow the formulation of a general prediction scheme. During the analysis, the following model was used:

$$VitD3_{fin} = a + (b \cdot VitD3_{init}) + (c \cdot \ln(T)) + (d_1 \cdot Gender) + (d_2 \cdot \text{Age}), \quad (3)$$

Where: $VitD_{3fin}$ and $VitD_{3init}$ are the target 25-(OH) D_3 serum levels and the initial test values, respectively;

T is the time (in months, 1–12);

Gender is the patient's sex (male = 1, female = 0);

Age is the number of full years at the time of initial testing;

a, b, c, d_1, and *d_2* are model coefficients.

The following results were obtained: *a* = 26.739 – baseline vitamin D level; *b* = 0.471 – weight of the initial vitamin D level; *c* = 11.889 – influence of supplementation duration (ln(T)); *d_1* = –0.452 – sex correction factor; *d_2* = –0.221 – age correction factor.

The adjusted R-squared value was 0.7335, indicating high predictive performance.

Example: Let us calculate the expected serum 25-(OH)D_3 level in a 35-year-old male after 6 months of taking "Solemax®", given an initial vitamin D level of 20 ng/mL:

$VitD_{3fin}$ = 26,739 + 9,42 + 21,32 – 0,452 – 7,735= 49,292.

It is important to note that this model is informative only for patients within the considered category and within 12 months of starting "Solemax®" therapy.

Analysis of 25-(OH)D_3 levels in patients of the NNT group revealed that, at the initial stage of observation, the median level in the 18–40 age group was 22.0 ng/mL (95% CI: 20.6–23.4), in the 41–60 age group – 20.2 ng/mL (95% CI: 19.1–21.3), and in individuals over 60 years old – 18.8 ng/mL (95% CI: 17.4–20.2). A further detailed analysis of the dynamics was not possible due to the lack of regular follow-up testing. However, by the 6-month follow-up point, a portion of patients (49.48%) had provided data, which allowed for a comparative analysis. The 18–40 age group showed a median level of 21.4 ng/mL (95% CI: 19.3–23.5), the 41–60 group – 18.3 ng/mL (95% CI: 16.9–19.6), and the over-60 group – 16.0 ng/mL (95% CI: 14.5–17.6). The decrease was statistically significant for the 41–60 age group (p = 0.03077) and for those over 60 years old (p = 0.01085). In the 18–40 age group, the reduction did not reach statistical significance (p = 0.6331). This dynamic may be explained by lifestyle changes commonly observed in the postoperative period, as well as the natural progression of vitamin D_3 deficiency with age, which is typical in the general population.

The presented data serve as the basis for assessing and interpreting BMD values in patients from the SRD and NNT groups. The analysis of this parameter is associated with several challenges. Firstly, CT scans, which are used to measure BMD, cannot be performed frequently due to the potential burden on the patient from ionizing radiation, as well as financial constraints. Secondly, BMD changes occur slowly, as they reflect long-term processes of bone tissue remodeling. Processes such as bone mass accumulation or the correction of osteopenia or osteoporosis require considerable time before measurable changes can be detected, making their registration difficult. The general dynamics of BMD change are presented in ***Fig. 5***. To provide a more comprehensive picture, the changes are presented as a percentage relative to the baseline value.

The data analysis revealed significant differences in bone tissue changes. Patients in the SRD group demonstrated a gradual increase in BMD, whereas a slight decrease was recorded in the NNT group. Notably, the actual intensity of changes remained minor. The maximum BMD increase by the 12th month of observation was 8.0% from baseline, while the maximum decrease was 5.2%. To assess the influence of various factors on the efficacy of therapy, as well as to determine the statistical significance of the observed dynamics given differences in examination timelines, regression analysis was applied. This approach enables the accommodation of time differences and a more precise quantification of the changes.

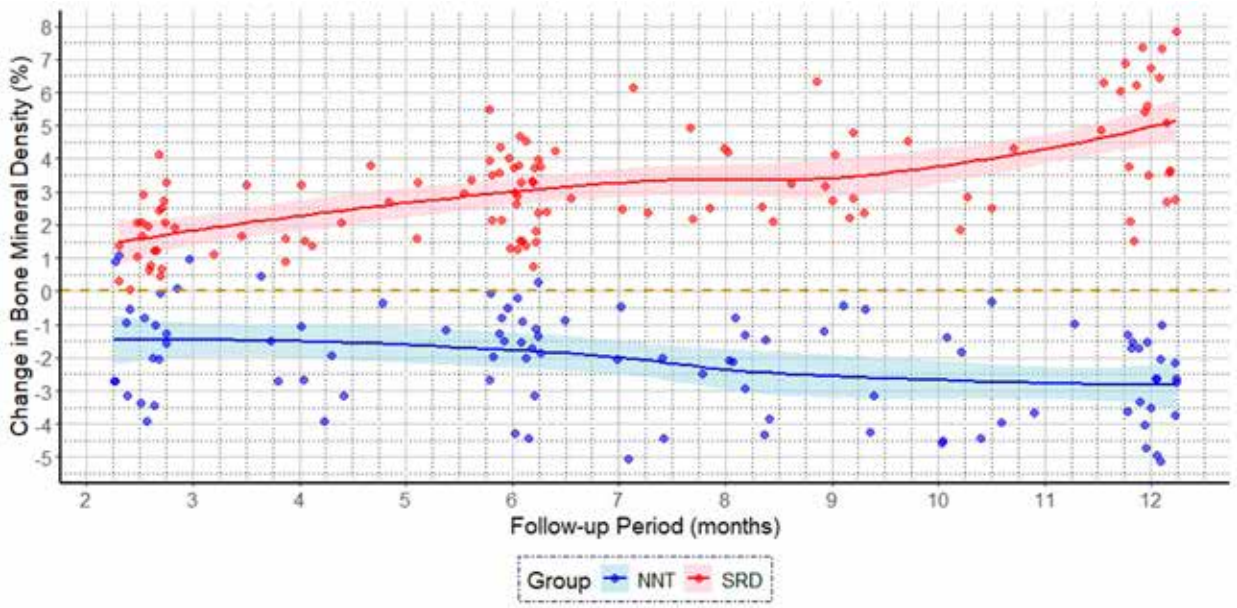

Fig. 5. BMD dynamics in patients. Changes are shown relative to baseline values

It was found that changes in the SRD group are better described by a logistic regression model. When evaluating the dependence of BMD on sex, age, duration of observation, and baseline serum 25-(OH)D_3 levels, it was established that the constructed model effectively describes the phenomenon under study: the adjusted R-squared was 0.6712, and the F-statistic was 59.18 ($p < 0.0001$).

Assessment of the "observation period" factor (coefficient = 1.643, $p < 0.0001$) indicated an exponential nature of the relationship, meaning the effect becomes more pronounced over longer observation periods. For instance, the difference in BMD gain between 6 and 12 months is substantial. As the baseline level of vitamin D increases, the BMD gain decreases (coefficient = −0.253, $p < 0.0001$). For example, an increase in the baseline vitamin D level from 15 to 28 ng/mL results in a 4.8% reduction in gain. This confirms that patients with lower baseline vitamin D levels show greater increases. At levels ≥30 ng/mL, the total gain does not exceed 0.5%. The effect of age (coefficient = −0.051, $p < 0.0001$) suggests that each additional year of age reduces the gain by 0.051%. For instance, the difference in gain between patients aged 30 and 50 years is approximately 1.02%. A sex-based effect was also identified (coefficient = 0.388, $p = 0.039$), indicating that males had, on average, a 0.388% greater BMD gain.

When assessing BMD for the NNT group, a linear regression model demonstrated the best predictive performance: the adjusted R-squared was 0.8955, and the F-statistic was 206.7 ($p < 0.0001$). Coefficient analysis showed that with increasing observation time, BMD reduction becomes more pronounced (coefficient = −0.122, $p < 0.0001$). Patients with higher vitamin D levels exhibited less BMD loss (coefficient = 0.089, $p < 0.0001$). With advancing age, the degree of BMD reduction increased (coefficient = −0.081, $p < 0.0001$). Males experienced less BMD loss compared to females (coefficient = 0.515, $p < 0.0001$).

In the final stage of analysis, the frequency and nature of complications were assessed ***(Table 2)***. The data presented refer to the number of implants, including each pedicle screw or interbody implant, allowing for a more objective complication analysis.

Detailed analysis of the nature of complications across patient groups has led to the following conclusions.

In the group with initially normal 25-(OH)D_3 levels, no screw loosening was recorded at any follow-up point. Three patients exhibited interbody implant migration, but further investigation revealed gross violations of postoperative care guidelines, likely contributing to this occurrence (it should be noted that this group was characterized by younger age and, consequently, a more active lifestyle). The displacements recorded two months after surgery did not progress and did not require surgical correction.

In the SRD group, loosening of four G1-grade screws was recorded in two patients. During dynamic follow-up, the severity of these findings did not progress, and no surgical correction was needed. Three cases of interbody implant migration within the vertebral body were registered at the 6-month follow-up. In one case, the migration worsened to G2 severity by the 8-month control check. No further negative dynamics were observed thereafter, and surgical intervention was not required.

The NNT group exhibited the highest rate of complications. Six months after surgery, loosening of 13 screws and migration of 5 cages were noted, and two patients underwent revision surgeries. After another 6 months, the number of cage displacements increased to 6, and the number of loosened screws increased to 25. Six revision surgeries were performed.

Most of the mentioned complications had no clinical manifestations. For instance, displacement of a cage within the vertebral body was often asymptomatic and did not adversely affect the patient's condition. G1-grade screw loosening was typically a radiological finding that did not require clinical intervention. However, it should be taken into account that many surgeons do not recommend routine follow-up CT scans to their patients,

Table 2. Frequency and nature of postoperative complications associated with implant placement

Indicator	0–6 months			0–12 months		
	NNC	**SRD**	**NNT**	**NNC**	**SRD**	**NNT**
Screws						
G0	44	256	251	44	256	239
G1	–	4	10	–	4	14
G2	–	–	2	–	–	5
G3	–	–	1	–	–	4
G4	–	–	–	–	–	2
Cages						
G0	25	85	62	25	85	60
G1	2	3	3	2	2	3
G2	1	–	1	1	1	2
G3	–	–	1	–	–	1
Surgical correction	0	0	2	0	0	6

which may limit the detection of such complications. Therefore, our data may significantly exceed those of other studies on complications due to more rigorous radiological monitoring.

The conducted analysis allowed for the identification of certain findings scarcely covered in the literature. It was found that adequate correction of 25-(OH)D_3 levels can halt the process of screw loosening, thereby eliminating the need for revision surgeries. Insufficient levels of vitamin D_3 may result in interbody implant dislocation during the late postoperative period, which is traditionally considered uncharacteristic for the type of surgeries under discussion.

Statistical analysis supported the conclusion that correction of 25-(OH)D_3 levels using "Solemax®" significantly reduces the risk of postoperative complications. Within the first 6 months post-surgery, the risk of screw loosening decreased by 69.84% (odds ratio [OR] – 0.3016), and the risk of interbody implant migration – by 56.2% (OR – 0.438). After one year of follow-up, the risk reduction amounted to 85.06% (OR – 0.1494) for screw loosening and 64.7% (OR – 0.353) for PLIF implant migration. However, it is evident that such a reduction in risks cannot be attributed solely to the positive effect of 25-(OH)D_3 on BMD, as the changes in this parameter during the observed period were not sufficient to explain the magnitude of the effect. It is likely that the identified correlation is related to more complex mechanisms, some of which are discussed below.

Clinical Case

Patient S., 59 years old, underwent surgical intervention due to instability of the L5–S1 segment on the background of Spina bifida at S1. An interbody corporodesis was performed using a PEEK cage along with transpedicular fixation at the L5–S1 level. During screw placement, looseness of the bone tissue was noted. The BMD index of the L1 vertebral body was 85 HU. The level of 25-(OH)D_3 measured 10 days postoperatively was 18.7 nmol/L. The patient was advised to undergo an examination to rule out osteoporosis and, if necessary, initiate appropriate therapy.

Four months after surgery, a follow-up examination revealed early signs of screw instability graded G1 in the S1 vertebral body ***(Fig. 6B)***. The patient provided DEXA scan results indicating early signs of osteopenia and a conclusion from the endocrinologist stating that no specific therapy was required.

Eight months postoperatively, due to the onset of dull pain in the postoperative area, a control CT scan was performed ***(Fig. 6C)***, which revealed progression of screw instability to grade G2. At month 11, a revision surgery was carried out. The screws were replaced with larger-diameter screws impregnated with polymethylmethacrylate, and additional screws were placed in the iliac wings to reinforce the fixation.

Discussion

In assessing the effectiveness of using vitamin D_3 for the prevention of complications associated with implant placement, a brief overview of its biological effects and impact on the skeletal system is necessary for proper interpretation of the obtained results. It is known that approximately 80–90% of vitamin D_3 is synthesized in the skin under the influence of ultraviolet radiation, while 10–20% is obtained from food sources [30]. This ratio depends on a number of factors, including lifestyle, climate, geographical latitude, skin pigmentation, age, and dietary habits. For instance, in populations residing at higher latitudes (e.g., Scandinavian countries and Canada), cutaneous synthesis of vitamin D_3 decreases during the autumn and winter months, shifting the ratio toward dietary sources. It has been established that the peak intensity of synthesis occurs under direct sun exposure at midday, with an optimal wavelength range of 295–315 nm (UVB spectrum) [31].

The precursor of vitamin D in the skin is 7-dehydrocholesterol, a cholesterol derivative found primarily in the deeper layers of the epidermis. Ultraviolet exposure triggers a photochemical reaction resulting in the cleavage between the 9th and 10th carbon atoms in the ring structure of 7-dehydrocholesterol, forming an unstable compound, previtamin D_3. Within several hours, body heat induces thermal isomerization of this compound into a stable form – vitamin D_3

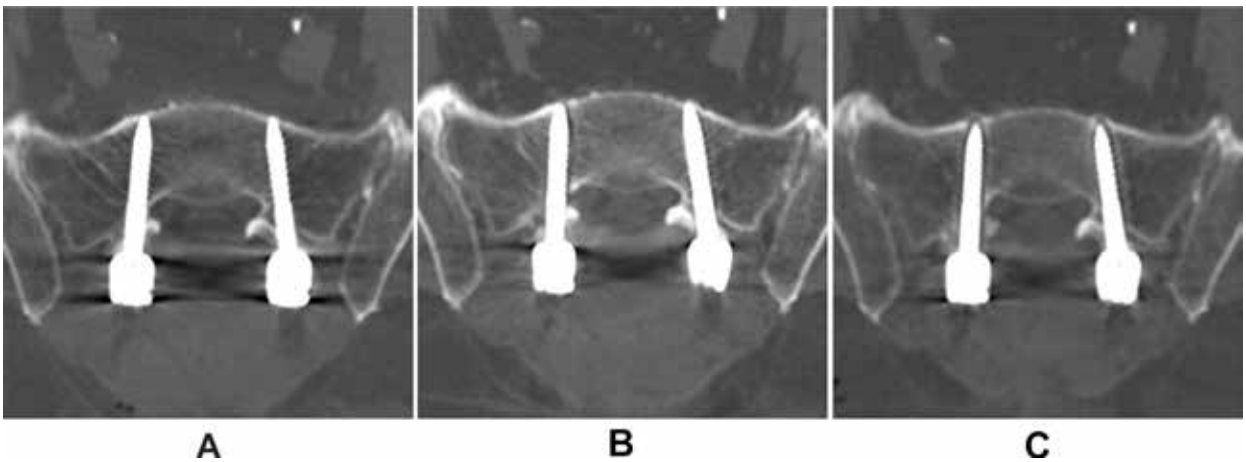

Fig. 6. MSCT results of patient S.: A – 3 days after surgical intervention; B – after 4 months; C – after 8 months.

(cholecalciferol). Several studies have shown that with excessive UVB exposure, previtamin D_3 can be converted into other metabolites such as toxisterol or lumisterol, which do not initially participate in calcium metabolism but possess antioxidant properties [32, 33]. This mechanism serves as a safeguard against excessive production of vitamin D_3 [34]. The greater the surface area of skin exposed to sunlight, the more vitamin D_3 is synthesized. Research indicates that even UVB exposure to as little as 5% of skin surface area (e.g., the face and hands) can significantly affect serum levels of 25(OH) D [35, 36]. Sunscreens with SPF ≥50 reduce vitamin D_3 synthesis by 75–90% [37]. Additionally, melanin in the skin absorbs ultraviolet radiation, thereby reducing its availability for vitamin D_3 synthesis. As a result, individuals with darker skin (Fitzpatrick skin types V and VI) exhibit a slower synthesis rate [38]. With aging, the level of 7-dehydrocholesterol in the epidermis decreases, leading to a reduced capacity for vitamin D_3 synthesis. Consequently, elderly individuals are more vulnerable to vitamin D deficiency, especially when sun exposure is limited [39].

The second route of cholecalciferol entry into the body is alimentary—primarily through the consumption of animal-derived foods. However, it has been noted that achieving adequate vitamin D intake through a standard diet is difficult. In several countries, this deficiency is compensated through the use of vitamin D-fortified foods or dietary supplements [40, 41]. Research by D.R. Fraser demonstrates that endogenously synthesized vitamin D_3 possesses higher biological activity compared to exogenously obtained vitamin D_3 [42].

Once in the bloodstream, vitamin D_3 almost immediately binds to transport proteins, which protects it from degradation and helps maintain its concentration in circulation. More than 85% of cholecalciferol is transported by vitamin D-binding protein (DBP), which exhibits a high affinity not only for vitamin D itself but also for its hydroxylated forms [43, 44]. Approximately 15% is transported by albumin; however, due to its lower binding specificity, this mode of transport facilitates faster cellular uptake of vitamin D [45]. Less than 1% of vitamin D_3 exists in its free form, which is considered biologically active and capable of entering cells to activate the expression of genes involved in calcium homeostasis, immune response, cell proliferation, and differentiation [46].

The liver is the primary organ involved in the initial stage of vitamin D_3 metabolism. Cholecalciferol, bound to DBP, is delivered to the liver via the portal vein or systemic circulation. The DBP–vitamin D_3 complex is recognized by specific receptors on the hepatocyte membrane, resulting in endocytosis that enables the intracellular entry of vitamin D_3. Within the cell, it undergoes hydroxylation catalyzed by the enzyme 25-hydroxylase (CYP2R1), producing 25-hydroxyvitamin D_3($25(OH)D_3$), which represents the main circulating form of the vitamin [47]. The resulting $25(OH)D_3$ binds to DBP and re-enters the bloodstream, from where it is transported to the kidneys for further activation or stored in depots, primarily adipose tissue [43]. The concentration of $25(OH)D_3$ is commonly used as a biomarker for assessing vitamin D status in the body, as it reflects the combined vitamin D_3 intake from both skin synthesis and dietary sources, although it possesses very low biological activity [44].

The next stage of metabolism involves the hydroxylation of the biologically less active calcidiol ($25(OH)D_3$) to form calcitriol ($1,25(OH)_2D_3$)—the active form of vitamin D_3, which performs key biological functions in the body within the context of the processes analyzed in this study. This transformation process occurs under the action of the enzyme 1α-hydroxylase (CYP27B1). Under conditions of relative homeostasis, approximately 85–90% of $1,25(OH)_2D_3$ is synthesized in the kidneys, while 10–15% is produced in other tissues, primarily bone, cartilage, and connective tissues. It has been established that bone structure restoration, such as after trauma, can significantly alter this ratio in favour of local transformation. Calcidiol is transported through the renal arterioles to the epithelium of the proximal convoluted tubules in the form of the DBP-$25(OH)D_3$ complex. Endocytosis occurs here via megalin and cubilin receptors, and hydroxylation at the 1α-position of $25(OH)D_3$ takes place intracellularly. CYP27B1, being the key enzyme in the activation of vitamin D_3, represents a crucial regulatory point in this process via mechanisms of both positive and negative feedback regulation [48]. Specifically, direct stimulation of CYP27B1 gene expression in proximal tubule cells of the kidneys is observed during hypophosphatemia and under the influence of parathyroid hormone (PTH). Elevated calcium levels can inhibit the activity of CYP27B1 either directly in the proximal tubule cells or indirectly by stimulating calcium-sensing receptors (CaSR) on parathyroid gland cells, leading to suppressed PTH secretion [49].

It is noted that calcitriol synthesized in the kidneys primarily exerts systemic effects. In the intestines, for example, $1,25(OH)_2D_3$ plays a key role in enhancing the absorption of calcium and phosphate. Calcitriol enters the epithelial cells of the small intestine (mainly the duodenum and jejunum) and binds to vitamin D receptors (VDRs) located in the cell nucleus. The calcitriol-VDR complex activates the expression of genes responsible for the synthesis of a number of transport proteins: Calbindin-D—a calcium-binding protein that transports calcium through the cytoplasm of enterocytes from the apical membrane to the basolateral membrane; TRPV6 (a calcium channel)—a channel located on the apical membrane of enterocytes through which calcium enters the cell from the intestinal lumen; PMCA1b (a calcium pump)—a protein on the basolateral membrane that actively transports calcium from the cell into the bloodstream; NaPi-IIb (a sodium-phosphate cotransporter), which transfers phosphates from the intestinal lumen into the cell along with sodium ions, etc. [50]. Moreover, $1,25(OH)_2D_3$ enhances the reabsorption of calcium and phosphate in the proximal tubules, thereby reducing their urinary excretion. It also regulates immune cell functions (including macrophages, T-lymphocytes, and dendritic cells) by modulating the inflammatory response, suppresses the synthesis of pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α), participates in the regulation of the renin–angiotensin–aldosterone system by inhibiting the expression of the renin gene in the juxtaglomerular cells of the kidneys, which leads

to decreased production of angiotensin II—a potent vasoconstrictor and a contributor to elevated blood pressure. Additionally, it improves endothelial function by increasing the synthesis of nitric oxide, which promotes vasodilation, inhibits vascular wall mineralization by reducing the expression of osteopontin and β-glycan and increasing the production of matrix Gla-protein (MGP), and improves myocardial contractility through modulation of intracellular calcium levels [51, 52].

In the context of the analyzed issue, significantly greater interest lies in the local synthesis of $1,25(OH)_2D_3$ within bone tissue, since renal calcitriol plays a leading role in supplying the bone with calcium and phosphate via systemic calcium-phosphorus homeostasis, whereas local $1,25(OH)_2D_3$ is crucial for the fine-tuned regulation of bone remodeling and regeneration processes. Upon entering from the bloodstream in the form of DBP-25(OH)D_3, calcidiol is converted into calcitriol in all major types of bone cells (osteoblasts, osteoclasts, and osteocytes) via the enzyme CYP27B1 [53]. The primary mechanism of intracellular transport of the DBP-25(OH)D_3 complex is mediated by megalin, which is predominantly expressed in osteocytes and osteoblasts of bone tissue. Several studies demonstrate a significant age-related decline in megalin expression, particularly in proximal tubular cells of the kidneys, which reduces substrate availability for $1,25(OH)_2D_3$ synthesis due to diminished reabsorption of DBP-25(OH)D_3 from the bloodstream [54]. A similar trend in bone tissue has not been definitively proven, although a general age-associated decline in the activity of osteoblasts and osteocytes has been verified, which may indirectly affect intracellular transport of DBP-25(OH)D_3. Furthermore, an age-related decrease in systemic CYP27B1 activity has been recorded, which is of fundamental significance for the development of osteoporosis. A number of experimental studies in animals demonstrate a nearly linear correlation between the age-related decline in CYP27B1 activity in bone tissue and the reduction in BMD [55,56].

Unlike the renal parenchyma, where CYP27B1 expression is regulated by systemic factors, in bone tissue, the primary stimuli for the expression of this enzyme are mechanical loading, bone tissue damage, and the inflammatory response [57]. These local stimuli activate CYP27B1, promoting the synthesis of calcitriol, which participates in the local regulation of bone metabolism and ensures a certain degree of autonomy in both adaptive and reparative processes [58].

It is well established that bone tissue is capable of dynamically responding to mechanical forces within physiological limits. In fact, the microarchitecture of bone is shaped by habitual mechanical loading, maintaining a balance between strength and mass economy [59]. The trabecular structure of the spongy substance of the vertrbra, according to Wolff's law, clearly reflects the vectors of compression and tension generated during axial and lateral loading [60]. The fundamental structural-functional element of bone tissue responsible for remodeling in response to mechanical load is the osteocyte—a cell located within lacunae in the mineralized matrix and interconnected through a canalicular system filled with interstitial fluid. Mechanical loading induces micro-deformations in the bone, causing interstitial fluid to flow through the canaliculi surrounding osteocyte processes. This results in the activation of mechanoreceptors and ion channels, triggering a cascade of intracellular signals. The main pathways involved are the Wnt/β-catenin signaling pathway, prostaglandins (PGE_2), and nitric oxide, which stimulate nearby osteoblasts and increase the expression of CYP27B1 [61, 62].

In response to mechanical injury to bone tissue, a complex process is initiated that involves an inflammatory reaction and remodeling aimed at restoring bone structure and function. The initial stage of this pathophysiological process is the production of pro-inflammatory mediators (IL-1β and TNF-α) by osteoblasts and macrophages, which in turn stimulate CYP27B1 expression in bone cells. The increased synthesis of calcitriol accelerates the remodeling of damaged bone by stimulating osteoblasts and the production of bone matrix, while the activation of osteoclasts via the RANKL/OPG system serves to remove damaged tissue [63, 64].

Calcitriol synthesized locally within bone tissue exerts a potent anti-inflammatory effect. Upon binding to the VDR, it suppresses the expression of genes encoding key pro-inflammatory cytokines (IL-1β, TNF-α, and IL-6), while simultaneously stimulating the production of anti-inflammatory cytokines (IL-10 and transforming growth factor-beta, TGF-β). Under its influence, macrophage polarization shifts from the pro-inflammatory M1 phenotype to the anti-inflammatory M2 phenotype. Additionally, calcitriol inhibits the activation of Th17 cells, which produce IL-17—a cytokine associated with bone tissue destruction [65]. Calcitriol also plays an important role in the regulation of osteoclastogenesis: it decreases RANKL expression while enhancing the synthesis of osteoprotegerin (OPG), which binds to RANKL and prevents its interaction with the RANK receptor, thereby limiting osteoclast activity [66]. This mechanism allows for a balanced inflammatory response at the initial stage, enabling the osteolysis of damaged structures while preventing excessive bone degradation and the transition to a chronic inflammatory state. Thus, calcitriol counteracts the hyperactivation of osteoclasts characteristic of chronic inflammation and contributes to the preservation of bone mass by maintaining the balance between bone resorption and regeneration [67]. This mechanism is particularly critical for preventing the destructive consequences of prolonged inflammatory processes.

The simplified mechanism of vitamin D biological activity in bone tissue described above—both under physiological conditions and in the presence of pathology—provides a rationale for a pathogenetic approach to correcting its deficiency during surgical spinal stabilization using implants. From a pathophysiological standpoint, the process of implantation involves bone tissue damage, an inflammatory response, and load redistribution. This process can be illustrated using the example of transpedicular stabilization. The placement of transpedicular screws results in mechanical destruction of trabecular and, to a lesser extent, cortical bone, which induces a local tissue response (activation of osteoclasts, osteoblasts, and immune cells, initiating bone remodeling). In response to injury,

proinflammatory mediators (IL-1β, TNF-α, IL-6) are released, which stimulate osteoclastogenesis and recruit macrophages and other immune cells. The inflammatory response plays a dual role: on the one hand, it prepares the contact area for subsequent healing and osseointegration; on the other hand, excessive activation may lead to increased bone resorption and decreased screw stability [68]. Furthermore, the installation of transpedicular screws alters the biomechanical environment of the spine: the screws absorb part of the load, redistributing it between the bone and the implant [69]. This necessitates an adaptive response of the bone tissue surrounding the screws, manifested in enhanced activation of osteoblasts to form new bone tissue and ensure construct stability [70].

In the context of the issue under analysis, and based on current research devoted to the pathophysiology of bone tissue, it can be concluded that the stability of spinal fusion is determined more by the adequacy of bone tissue response to implantation than by absolute BMD values. Thus, even in cases of low BMD, successful osseointegration and adaptive remodeling can provide sufficient stability, provided there is an adequate distribution of load; conversely, when bone mineral density is normal but the tissue response to implantation is insufficient, the risk of construct instability remains high. This conclusion is supported both by the results of our study and by findings from other authors, though it requires further comprehensive investigation due to its clinical significance [71, 72].

Overall, the data we obtained demonstrate the advisability of correcting vitamin D levels in patients who have undergone spinal surgery involving the installation of various types of implants (including transpedicular fixation systems and cages for interbody fusion). This is supported by data from a limited number of studies. For example, Yong Xu et al. conducted an analysis of the efficacy of using $1,25(OH)_2D_3$ following TLIF (transforaminal lumbar interbody fusion) [73]. The authors noted that six months after surgery, the interbody fusion rate was 76.19% in the treatment group versus 43.48% in the comparison group ($p = 0.03$). Further follow-up revealed rates of 95.24% and 65.22%, respectively ($p = 0.02$). Moreover, in patients receiving $1,25(OH)_2D_3$, the Oswestry Disability Index (ODI) scores at all stages of follow-up were statistically significantly lower than in the comparison group.

V.M. Ravindra et al. reported results from a prospective observational study examining the frequency and rate of fusion and stability of spinal fusion in patients who underwent elective surgery using transpedicular screws [74]. Comparing patient groups with vitamin D deficiency (<20 ng/mL), insufficiency (20–30 ng/mL), and normal levels (>30 ng/mL), a significant increase in the median time to achieve fusion was observed (12, 8, and 6 months, respectively; $p = 0.001$). Furthermore, a multivariate analysis considering age, sex, and fusion length showed that vitamin D deficiency is an independent factor associated with failure to achieve adequate bony fusion. Similar results were obtained by other researchers [75, 76].

A review of the existing literature reveals that a number of studies are dedicated to the impact of baseline vitamin D levels and their correction on the overall efficacy of elective spinal surgery, which affects quality of life and is assessed using specialized questionnaires. Thus, Hao-Wei Xu et al., based on an evaluation of outcomes in 360 patients who underwent PLIF or TLIF procedures combined with transpedicular screws, determined that preoperative $25(OH)D_3$ deficiency is associated with poorer outcomes on the Visual Analogue Scale (VAS), the Japanese Orthopaedic Association (JOA) questionnaire, and ODI in the early postoperative period [77]. Similar findings were reported by Tae-Hwan Kim et al. [78]. These researchers analyzed outcomes in 31 female patients who underwent decompressive-stabilizing surgery on the lumbar spine for spinal canal stenosis. Treatment outcomes were assessed using the EuroQol-5D quality of life questionnaire and ODI. It was established that, in the postoperative period, correction of $25(OH)D_3$ levels was statistically significantly correlated with the patients' subjective evaluations of the surgical outcomes.

This phenomenon pertains to another aspect of vitamin D influence that is not addressed in this study. It is well-established that the stability of the spinal motion segment, both under normal conditions and post-surgery, is determined not only by the condition of the bone structures but also, to a significant extent, by the state of the ligamentous apparatus [79]. The degree of influence of the latter is inversely proportional to the rigidity of the applied fixation, yet it almost always contributes to the provision of stability [80]. The primary component that determines the mechanical properties of the human spinal ligamentous apparatus are type I and III collagens (COL1 and COL3) and elastin (ELN), whose concentrations vary across different ligaments. Thus, in the posterior ligamentous complex, which has the most significant impact on spinal motion segment stability, the ratio of COL1, COL3, and ELN is as follows: in the supraspinous ligament – 90–95%, 5–10%, and <5% respectively; in the interspinous ligament – 70–80%, 20–30%, and 5–10%; in the ligamentum flavum – 20–30%, 5–10%, and 60–70%; and in the posterior longitudinal ligament – 80–85%, 10–15%, and 5% [81].

A number of studies have demonstrated that in cases of ligamentous apparatus injury, which is inevitable during surgical intervention, vitamin D levels often become a critical factor influencing the speed and quality of regeneration [82]. Vitamin D activates VDRs in fibroblasts, enhancing their proliferative activity and increasing the expression of genes encoding COL1, COL3, and ELN. This contributes to the restoration of the structure of damaged ligaments, inhibits collagenase activity—thereby preserving ligament integrity and preventing degradation—and stimulates angiogenesis through the production of vascular endothelial growth factor (VEGF), ensuring oxygen and nutrient delivery to damaged tissues and accelerating healing. Furthermore, vitamin D regulates the activity of matrix metalloproteinases and their inhibitors, thereby enabling balanced degradation of the damaged matrix and synthesis of new matrix components. It promotes the differentiation of mesenchymal stem cells into fibroblast-like cells, increasing their role in regeneration, and modulates immune responses, protecting the injury site from secondary infection and creating a favorable environment for healing [83]. These mechanisms have

a significant indirect impact on the effectiveness of spinal fusion and on the overall outcome of surgical intervention.

One of the most effective strategies for enhancing the effects of vitamin D on bone tissue, according to contemporary research, is its combined use with vitamin K_2 [84,85]. Vitamin K_2 (menaquinone, MK) is a fat-soluble vitamin that plays a crucial role in calcium metabolism, as well as in maintaining the normal metabolism of bone tissue and cardiovascular health. The main sources of menaquinones include fermented foods (e.g., natto, cheese, sauerkraut) and animal products (e.g., egg yolk, liver, fatty fish). Vitamin K_2 exists in several forms, among which MK-4 and MK-7 are the most significant, differing in metabolic activity and bioavailability. MK-4 is the only form of menaquinone synthesized in the human body. The substarate for synthesis is phylloquinone vitamin K1, which is obtained from dietary sources, primarily green leafy vegetables (spinach, broccoli, cabbage) and plant oils. The key enzymes involved in the conversion of K1 to MK-4 are NAD(P)H reductase and isoprenoid transferase, and this process occurs directly within the tissues where MK-4 performs essential biological functions. A distinctive feature of MK-4 is its high bioavailability and short half-life; its tissue levels depend on the presence of vitamin K1 in the diet. In contrast, MK-7, which is obtained solely through dietary intake, has a long side chain composed of seven isoprenoid units. This structure ensures high stability and a half-life of approximately 72 hours, making it particularly effective when consumed regularly in low doses, as it accumulates in the body [86].

The primary mechanism by which vitamin MK influences bone tissue metabolism—justifying its use alongside vitamin D3—lies in the activation of osteocalcin, a protein involved in bone mineralization. Osteocalcin is synthesized by osteoblasts in an inactive form, and MK plays a key role in its activation by serving as a cofactor for the enzyme γ-glutamyl carboxylase. This enzyme catalyzes the addition of γ-carboxyl groups to glutamic acid residues. The activated form of osteocalcin exhibits high affinity for calcium and hydroxyapatite crystals ($Ca_{10}(PO_4)_6(OH)_2$), the main mineral component of bone tissue. Upon binding to these components, osteocalcin is integrated into the mineral matrix, fulfilling a stabilizing function and ensuring the structural integrity of the bone. This process promotes effective mineralization of bone tissue and supports its mechanical strength [87].

In addition, MK reduces the risk of vascular calcification, preserving vascular elasticity and preventing the development of atherosclerosis. A key player in preventing calcium salt deposition in soft tissues is matrix Gla-protein (MGP)—a protein primarily synthesized by vascular smooth muscle cells, chondrocytes, and bone cells. Its expression is regulated by vitamin D through binding to the vitamin D receptor VDR, which enhances gene transcription and increases MGP mRNA synthesis. MGP activation occurs in the endoplasmic reticulum via γ-glutamyl carboxylase, which also uses vitamin K_2 as a cofactor. Following γ-carboxylation, activated MGP is transported from the cell into the extracellular matrix, where it binds calcium ions, preventing their precipitation and the formation of hydroxyapatite crystals in soft tissues [88]. Calcium ions bound by activated MGP are returned to the bloodstream through the action of specific cellular transport systems. Voltage-gated calcium channels (VGCC) facilitate the passive influx of calcium into cells along the concentration gradient, while Plasma Membrane Ca^{2+}-ATPase (PMCA) actively exports calcium from endothelial cells into the bloodstream. This process maintains calcium homeostasis, prevents pathological vascular calcification, and preserves vascular functionality by ensuring arterial wall elasticity and reducing the risk of atherosclerosis [89].

Thus, beyond the evident synergism in maintaining normal bone metabolism, the combined use of vitamin D3 and MK is significantly safer—particularly in preventing pathological calcification of soft tissues and ensuring optimal calcium distribution in the body. The administration of D3 without K2 carries the risk of elevated free calcium levels that cannot be effectively redirected into bone tissue. In contrast, their co-administration creates a balanced calcium regulation system, thereby minimizing associated risks [90].

The aforementioned data obtained from *in vitro* studies have been confirmed in clinical practice. For instance, Jun Iwamoto et al. conducted an evaluation of the effects of combined administration of vitamins D_3 and K_2 on BMD of the lumbar spine in postmenopausal women with verified osteoporosis [91]. The study included 92 postmenopausal women diagnosed with osteoporosis who had been in menopause for over five years and were aged between 55 and 81 years. The participants were randomized into four treatment groups: the first group received vitamin D_3, the second — vitamin K_2, the third — a combination of vitamins D_3 and K_2, and the fourth — calcium lactate. It was found that intake of either vitamin D_3 or vitamin K_2 over a period of two years significantly increased BMD of the lumbar spine, whereas calcium intake led to a significant decrease in this parameter. Combined administration of vitamins D_3 and K_2 resulted in a marked increase in lumbar spine BMD, more pronounced than in monotherapy with either vitamin D_3 or K_2. A similarly designed study was conducted by Takahisa Ushiroyama et.al [92]. A total of 172 women aged 55–81 years, who had signs of osteoporosis or osteopenia according to BMD measurements, were divided into four statistically equivalent groups. These groups received vitamin K_2, vitamin D_3, combined therapy with vitamins K_2 and D_3, or dietary support alone. The latter group was provided with recommendations to increase intake of foods rich in vitamins D_3 and K_2, consume 800–1000 mg of calcium daily (primarily from dairy products such as milk and yogurt), take mineral supplements, engage in moderate physical exercise, and spend at least 15 minutes per day in direct sunlight. A significant increase in BMD was observed in 45.2% of patients in the combined therapy group, in 9.4% of the K_2 group, and in 23.3% of the D_3 group. Participants in the comparison group did not show significant improvement in BMD, and in some cases, a decline in the assessed parameter was noted. Similar findings are reported by other researchers [93–95].

We have considered only a small portion of the biological effects that demonstrate the clinical significance of correcting vitamin D_3 levels in patients who have undergone spinal surgery involving implants. The impact of vitamin D_3 on the incidence of inflammatory

complications, pain intensity, rehabilitation rate, and other aspects was not studied in this research. However, these issues require further investigation, as they significantly influence patients' quality of life and clinical outcomes. Further exploration of these aspects may broaden our understanding of the role of vitamin D_3 in the postoperative period and contribute to optimizing treatment strategies for such patients.

Conclusions

A high frequency of vitamin D deficiency and decreased BMD was recorded among patients undergoing elective spinal surgeries involving implants. A significant correlation was found between the level of 25-(OH)D_3 and bone tissue status.

Correction of vitamin D_3 levels using "Solemax®" demonstrated a pronounced laboratory effect: after four months of intake, the 25-(OH)D_3 level in all patients reached the reference values, indicating the efficacy of this therapy.

Regular "Solemax®" intake in the postoperative period had a positive effect on bone tissue condition. This was confirmed by an increase in BMD among patients receiving correction therapy, while a decrease in this parameter was registered in the comparison group.

A statistically significant reduction in the incidence of implant-related complications was observed in patients who received "Solemax®" starting from the early postoperative period. Regular intake reduced the risk of screw loosening by 69.84% and the risk of interbody implant displacement by 56.2% within the first 6 months post-surgery. After 1 year of follow-up, the risk reduction was 85.06% for screw loosening and 64.7% for PLIF implants.

The obtained results indicate that the stability of spinal fusion is determined primarily by the qualitative adaptive response of bone tissue to implantation rather than the absolute values of its mineral density. The use of a balanced combination of vitamins D_3 and K_2 significantly enhances the therapeutic effect, reduces the risk of postoperative complications, and improves clinical outcomes.

Disclosure

Conflict of interest

The company provided the investigational drug as a trial batch. No financial support was received from the company. The study design was developed by the authors. Data analysis and formulation of conclusions were conducted solely by the authors. The authors declare no conflicts of interest.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):28-36
doi: 10.25305/unj.320333

Clinical and demographic data and the significance of various dysfunctions and severity indicators in multiple sclerosis patients

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Received: 06 January 2025
Accepted: 17 February 2025

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Introduction: Visual and oculomotor disorders are frequent manifestations of nervous system damage in multiple sclerosis. Multiple sclerosis is associated with an increased risk of falls, degeneration of sensory organization, and a possible increased reliance on vision for balance control.

The clinical picture of multiple sclerosis is characterized by numerous neurological symptoms, among which visual and oculomotor disorders occupy a significant place. This is because the consequences of inflammation, demyelination, and neurodegeneration often negatively affect both the afferent and efferent parts of visual function, significantly worsening the quality of life of patients with multiple sclerosis.

Objective: To determine the clinical and demographic characteristics, the significance of nervous system dysfunction and disability, the degree of visual and oculomotor impairment, severity of pain, fatigue, depression, and cognitive impairments, quality of life indicators in patients with multiple sclerosis and to identify the peculiarities of their course in terms of comorbidity.

Materials and methods: A total of 216 patients with various forms of multiple sclerosis were examined. Clinical-demographic data, paraclinical characteristics of nervous system dysfunction and disability, severity of pain, fatigue, depression, cognitive disorders and quality of life indicators were analyzed.

Patients were assessed using the Functional System Scale (FS), Expanded Disability Status Scale (EDSS), an extended neuropsychological examination.

The presence and duration of comorbid diseases were clinically determined through laboratory and instrumental studies, as well as examinations by other specialists (ophthalmologist, therapist, cardiologist, rheumatologist, urologist, and dentist).

Results: When conducting a study of patients with multiple sclerosis of the general sample, symptoms associated with pyramidal functions impairment were in 191 patients (88.4%), symptoms caused by the cerebellar functions impairment - in 178 patients (82.4%), symptoms caused by brainstem and cranial nerve dysfunction – in 161 patients (74.5%), symptoms associated with impaired sensitivity functions – in 169 patients (78.2%), symptoms due to pelvic disorders – in 187 patients (87.0%), symptoms caused by impaired visual functions – in 116 patients (53.7%), symptoms associated with impaired cerebral (mental) functions – in 184 patients (85.2%).

In total, visual disorders were recorded in 116 (53.7%) patients with multiple sclerosis, among them - in 46 (21.3%) patients of I group (without comorbidity) and in 70 (32.4%) patients of II group (with presence of comorbidity), and oculomotor disorders - in 168 (77.8%) patients with multiple sclerosis, among them - in 77 (35.6%) patients of group I (without comorbidity) and in 91 (42.1%) patients of group II (with presence of comorbidity).

In patients with multiple sclerosis, according to the data of the FS-3 FS scale (oculomotor disorders), the average indicators were as follows: group I - 1.4 ± 0.3; group II - 1.6 ± 0.3, and according to the FS-6 FS scale (visual disorders), the average indicators were as follows: group I - 0.8 ± 0.2, group II - 1.4 ± 0.3.

Conclusions: 1. The prevalence of visual disorders of patients with multiple sclerosis was 56.0%, and oculomotor disorders - 85.2%.

2. Oculomotor disorders were more widely represented in patients with multiple sclerosis, which, in our opinion, is associated with damage to the structures of the posterior longitudinal bundle, which is often affected in multiple sclerosis due to the "dissemination in space" characteristic of the disease.

3.It was found that in patients with multiple sclerosis visual disorders were most clearly correlated with the level of depression and cognitive impairment. Oculomotor disorders in patients with multiple sclerosis were most clearly correlated with levels of fatigue.

4. In the group of patients with multiple sclerosis with comorbid pathology, visual and oculomotor disorders were significantly more prevalent.

Key words: *multiple sclerosis; clinical and demographic characteristics; visual disorders; oculomotor disorders; severity of pain; severity of fatigue; severity of depression; severity of cognitive impairment; quality of life indicators; comorbidity*

Introduction

Multiple sclerosis (MS) is a degenerative disease of the nervous system, the basis of the pathological mechanisms of which is the process of progressive demyelinating damage, primarily of the central nervous system. The clinical picture of MS is characterized by a wide range of neurological symptoms, among which visual and oculomotor disorders occupy a significant place because the consequences of inflammation, demyelination, and neurodegeneration often negatively affect both the afferent and efferent parts of visual function, significantly worsening the quality of life of patients with MS [1, 2, 3, 4, 5].

Retrobulbar neuritis is often one of the earliest manifestations of MS. Visual disorders, or afferent visual abnormalities — including decreased visual acuity and contrast sensitivity, binocular vision defects, visual field disturbances, changes in color perception due to retrobulbar neuritis in MS are frequent symptoms of exacerbation, occurring in 14-50% of patients with MS [5, 6, 7], while 77% of patients have subclinical changes in visual function [4]. As a result of acute retrobulbar neuritis, central scotomas usually appear in the affected eye, which leads to a decrease in visual acuity and contrast sensitivity, as well as a narrowing of the field of vision [2, 3]. Jasse L. et al., 2013 [8] showed, that more than a third of patients with MS have persistent visual disturbances. Hemianopsia may also occur in patients with MS; the degree of recovery varies depending on the degree of initial disturbance of the field of vision [2].

Medical treatment of acute retrobulbar neuritis can shorten the time of recovery of visual functions, but ultimately does not affect the quality and completeness of recovery [8]. Although in the case of acute retrobulbar neuritis there are often quite effective courses of methylprednisolone pulse therapy, sometimes in combination with plasmapheresis, which can accelerate the recovery of vision in approximately 70% of MS patients [9], the results of the treatment of visual function disorders in MS are generally contradictory [10]. Some researchers believe that there is no procedure or method of treatment that can improve visual functions in general. This unsatisfied need for the treatment of visual disorders in MS requires the development of new treatment methods that have a neuroprotective effect and are able to restore impaired functions in patients with MS [3, 4, 5].

Oculomotor disorders (efferent visual abnormalities) are also symptoms in MS patients, and may occur temporarily or permanently, appearing in parallel with visual disturbances or independently of them. Oculomotor disorders are more common in patients with a progressive course of MS (compared with relapsing), may be an indicator of demyelinating damage to the structures of the posterior cranial fossa representing a more difficult neurological prognosis [2, 3, 4, 5]. Oculomotor deficiency is most often associated with MS with internuclear ophthalmoplegia, which leads to diplopia [2]. All types of nystagmus can occur in MS patients, along with saccadic eye movements, oscillopsia (immovable objects appear to patients as moving), blurred vision or its blurring, ocular dysmetria and gaze paresis [2, 5].

Low efficiency of in the treatment in terms of restoration of visual and oculomotor functions is observed in patients with MS in the presence of comorbid diseases, cognitive disorders, depressive disorders, fatigue and premorbid visual disorders [11, 12, 13, 14].

Objective: To determine clinical and demographic characteristics, significance of nervous system dysfunction and disability, degree of visual impairment, degree of oculomotor impairment, severity of pain, severity of fatigue, severity of depression, severity of cognitive impairment, quality of life indicators in patients with MS and to find out the peculiarities of their course in terms of comorbidity.

Materials and methods

Study participants

A total of 216 patients with MS were examined. The research was carried out at the Department of Neurology and Reflexotherapy of the Shupyk National Healthcare University of Ukraine. The research was conducted in accordance with the Helsinki Declaration of Human Rights (1964), the Council of Europe Convention "On Human Rights and Biomedicine" (1997), and current regulatory legal acts of Ukraine. Informed consent to participate in the examination and treatment was obtained from all patients. The research protocol was approved by the local ethics committee (Ethics Committee of the Shupyk National Healthcare University of Ukraine, minutes of the KE No. 9 dated October 1, 2012).

Inclusion criteria

The inclusion criterion was diagnosis of "multiple sclerosis" with indicators of the course of the disease, such as the frequency of clinically pronounced exacerbations and the rate of neurological deficit progression. The survey did not include patients with MS aged under 18 or over 65 years of age, as well as with a degree of disability of more than 5.5 points on the Expanded Disability Status Scale (EDSS). The criteria for excluding patients from observation were: refusal of the patient or his relatives to participate in the study; inability to be observed throughout the entire period.

216 patients with multiple sclerosis with various forms of course who underwent complex outpatient or inpatient treatment in the period from 2007 to 2016 were monitored. The diagnosis of "Multiple Sclerosis" was made in accordance with the updated criteria of McDonald (2005; 2010) [15, 16], and the accompanying pathology was recorded in the outpatient chart by the relevant specialist or detected during the examination or through a questionnaire. Due to the fact that the study was conducted in the period from 2007 to 2016, all patients were evaluated according to the McDonald criteria 2005 (for patients with MS who were included in the study in 2007-2010) while the 2010 criteria were used for MS patients enrolled between 2011 and 2016 for the diagnosis of multiple sclerosis. The 2017 revision of the McDonald criteria was not used in this study.

Group characteristics

All 216 patients with MS examined by us with different forms of the course, depending on the presence or absence of comorbid pathology, were divided into 2 groups: group I - patients without any concomitant

disease (109 patirents); group II- patients with one or more concomitant diseases (107 patients).

Group II consisted of 107 patients with MS, who at the time of examination had a clinically significant comorbid pathology, the data of which were revealed through a detailed survey of patients during an objective examination and analysis of medical records. At the same time, in group II 40 (18.5%) patients with MS had one comorbid pathology, 27 (12.5%) patients had two comorbid pathologies, 21 (9.7%) patients had three comorbid pathologies, and 19 (8.8%) patients had four or more comorbid pathologies.

The average age in the study group was 39.9 ± 9.7 years. The gender ratio (female/male) was approximately 7:4 (141 females/75 males), which confirms the data of modern researchers about the predominance of women among patients with MS. Regarding the marital status of patients with MS, married people prevailed in the study group - 60.7% (131: 85).

Among 216 patients, 96 (44.4%) with relapsing course of MS, the stage of exacerbation of the disease of various degrees of severity was registered, and in 43 (19.9%) patients – the stage of remission. Among patients with a progressive course of MS, 54 (25.0%) had a gradual deterioration of neurological deficit with slow dynamics, and 23 (10.7%) had a more rapid progression of symptoms.

Research design

A prospective comprehensive examination was conducted: clinical-neurological, neuropsychological, electrophysiological, ultrasound, MRI, laboratory examination of 216 patients (75 men and 141 women) aged 21 to 62 years (mean age 39.9 ± 9.7 years) diagnosed with MS according to the McDonald criteria (2005; 2010) with various forms of course (remitting and progressive) with a degree of disability ranging from 1 to 5.5 points on the EDSS scale (mean score 3.8 ± 1.3), with and without comorbid diseases, who underwent comprehensive outpatient or inpatient treatment at the clinical base of the Department of Neurology and Reflexotherapy (neurological departments of the Kyiv Regional Clinical Hospital) in the period from 2007 to 2016. The duration of observation for each patient was two years.

The clinical condition of the patients was described in accordance with the FS scale, and the degree of severity of neurological deficit - based on research data on the EDSS [17].

For the convenience of generalizing the symptoms of MS and adequately assessing the picture of the disease, the functional system lesion classification, proposed by J. F. Kurtzke, was used, which contains 7 sections for the assessment of: 1) pyramidal functions; 2) cerebellar functions; 3) brain stem and cranial nerves functions; 4) sensitivity functions; 5) bowel and bladder functions; 6) visual functions; 7) cerebral (mental) functions.

Each category is scored based on the severity of dysfunction, from less pronounced to more pronounced. The number of points is estimated for each scale separately (from FS-1 to FS-7). The use of this scale allows not only to obtain an in-depth clinical characteristic, but also to conduct dynamic monitoring of the course of the disease in patients with MS. We determined the level of disability using EDSS. During the neurological examination of patients with MS, we found the presence or absence of visual and oculomotor disorders, as well as in the anamnesis, after the diagnosis of multiple sclerosis, their nature was clarified. When determining the degree of FS-6 impairment (visual functions), the evaluation was performed on the more affected eye. Before determining the degree of damage to the FS-6, a mandatory ophthalmologic evaluation was performed, including measurement of visual acuity (with and without correction), fundus examination, and assessment of visual fields ***(Table 1)***.

Table 1. Assessment of visual and oculomotor functions according to the FS-6 and FS-3 scales by J. Kurtzke

Assessment of the degree of impaired functions in points	**Points**	**FS-3 Brain stem and cranial nerves functions**	**FS-6 (visual functions)**
	0	Norm	Norm
	1	Signs of dysfunction without disability	Scotoma with visual acuity (corrected) better than 0.6 (20/30); pallor of the temporal halves of the discs of the optic nerves
	2	Moderate nystagmus or other mild disorders	In the worse eye, scotoma and maximum visual acuity (corrected) from 0.6 (20/30) to 0.35 (20/59)
	3	Pronounced nystagmus, pronounced weakness of the oculomotor muscles or moderate impairment of other cranial nerves functions	In the worse eye, a large scotoma or moderate narrowing of the visual field, but the maximum visual acuity (with correction) from 0.35 (20/60) to 0.15-0.2 (20/99)
	4	Marked dysarthria or other significant impairments	In the worse eye, there is a marked narrowing of the field of vision and the maximum visual acuity (with correction) from 0.2 (20/100) to 0.1 (20/200); 3rd degree impairment plus maximum visual acuity in the better eye no more than 0.35 (20/60)
	5	Inability to swallow or speak	In the worse eye, the maximum visual acuity (with correction) is less than 0.1 (20/200); 4th degree impairment plus maximum visual acuity in the better eye no more than 0.35 (20/60)
	6	-	Disturbance of the 5th degree plus maximum visual acuity in the better eye no more than 0.35 (20/60)

A neuropsychological study was also conducted: manifestations of fatigue according Fatigue Severity Scale (FSS), pain according to the Visual Analogue Scale (VAS), level of depression according to the Beck Depression Inventory-II (BDI-II), cognitive function disorders according to the Mini-Mental-State-Examenations (MMSE) and indicators of quality of life were determined according to the SF-36.

Statistical analysis

For the purpose of statistical analysis of the study results, variational statistics methods were used to calculate the frequency characteristics of the studied indicators (%), average values (arithmetic mean – X) and estimate their variability (standard deviation – SD). To assess the statistical significance of clinical results and estimate the 95% confidence interval (CI), the mean error (m) was determined. In case of correspondence of the primary data to the parameters of the normal distribution, statistical analysis was performed using the Student's test, and in case of discrepancy – by generally accepted non-parametric methods: for quantitative indicators – the sum of Mann-Whitney ranks for two independent groups, Kruskal-Wallis rank analysis of variance for three independent groups, Dunnett's test (for comparison with the control group); for qualitative indicators – classical Pearson χ^2 -criterion with Yates' and Bonferroni corrections (for multiple comparisons), two-sided Fisher's exact criterion. To evaluate the data in dynamics, the Wilcoxon criterion (for comparing the indicators of one group) and the Kruskal-Wallis criterion (for comparing the indicators of several groups) were used. The assessment of the relationship between indicators was carried out by correlation analysis with Pearson's correlation coefficient. To compare observations before and after treatment, the Wilcoxon criterion was used for two dependent groups. The level of statistical significance was taken as $p < 0.05$. Statistical analysis was carried out using the standard SPSS software version 8.0.0 and Statistica 6.0.

Results

A total of 216 patients with MS were examined. An analysis of the entire patient cohort was performed. General clinical and demographic characteristics of patients are shown in ***Table 2***.

Clinical and demographic characteristics of patients with MS in connection with division into groups (comorbidity) are given in ***Table 3***.

Table 2. General clinical and demographic characteristics of patients

No.	Indicator	A general group of examined patients with MS (n = 216)
1	Average age, years (mean ± SD)	39.9 ± 9.7
2	Average age of onset of multiple sclerosis, years (mean ± SD)	28.7 ± 7.6
3	Duration of the disease, years (mean ± SD)	6.4 ± 3.5
4	Gender ratio (women / men, %)	62.3 / 37.7
5	Marital status (married, %)	60.7
6	Degree of disability for the EDSS, %	
	light	46.8
	average	53.2
	severe	-
	group average, points (mean ± SD)	3.8 ± 1.3
Type of course of multiple sclerosis		
7	Remitting, %	64.4
	Relapsing-remitting MS, %	42.6
	Relapsing-progressive MS, %	21.8
8	Progressive, %	35.6
	Primary progressive MS, %	20.8
	Secondary progressive MS, %	14.8
9	The presence of visual disorders, abs. (%)	116 (53.7)
10	The presence of oculomotor disorders, abs. (%)	168 (77.8)

Table 3. Clinical and demographic characteristics of patients with MS in connection with division into groups

No.	Indicator	A general group of examined patients with MS (n = 216)	
		group I (n = 109)	group II (n = 107)
1	Average age, years (mean ± SD)	36.9 ± 9.3	42.3 ± 10.4
2	Average age of onset of multiple sclerosis, years (mean ± SD)	28.4 ± 7.3	29.1 ± 7.9
3	Duration of the disease, years (mean ± SD)	5.3 ± 1.9	7.4 ± 2.0
4	Gender ratio (women/men, %)	66.1 / 33.9	64.5 / 35.5
5	Marital status (married, %)	57.8	63.5
6	Degree of disability by the EDSS, %		
	light	51.4	42.1
	average	48.6	57.9
	severe	-	-
	group average, score (mean ± SD)	3.4 ± 1,2	4.3 ± 1.4
7	VAS pain assessment, score (mean ± SD)	3.1 ± 1.3	4.8 ± 1.6
8	FSS fatigue assessment, score (mean ± SD)	3.3 ± 0.9	4.5 ± 1.3
9	Assessment of depression according to the Beck Depression Inventory-II (BDI-II), points (mean±SD)	11.5 ± 1.6	16.1 ± 1.9
9	Assessment of cognitive functions, (MMSE), score (mean ± SD)	27.93 ± 1.4	25.12 ± 2.3
10	Assessment of quality of life, SF-36, generalized indicators, scores (mean± SD)	PCS 43.1 ± 13.7 MCS 47.8 ± 12.5	PCS 32.2 ± 16.8 MCS 38.7± 11.5
11	The presence of visual disorders, abs. (%)	46 (21.3)	70 (32.4)
12	The presence of oculomotor disorders, abs. (%)	77 (35.6)	91 (42.1)

Note. PCS – physical component of health, MCS – mental component of health.

Ophthalmological examination revealed a decrease in visual acuity in 95 (44.0%) patients, visual field disturbances in 72 (33.3%), and change in color perception in 29 (13.4%). In 87 (40.3%) patients there was pallor of the temporal halves of the discs of the optic nerves. In total, visual disturbances occurred in 116 (53.7%) patients with MS of both groups, among them in group I - 46 (21.3%) patients, while in group II - 70 (32.4%). At the same time, in patients with MS according to the data of the FS-6 FS scale (visual disorders), the average indicators were as follows: group I - 0.8 ± 0.2; group II - 1.4 ± 0.3; and according to the severity of visual disturbances, the gradations were as follows: group I: 0 points – 63 (29.2%), 1 point – 21 (9.7%), 2 points – 14 (6.5%), 3 points – 11(5.1%); group II: 0 points – 37 (17.1%), 1 point – 30 (13.9%), 2 points – 18 (8.3%), 3 points – 16 (7.4%), 4 points – 6 (2.8%). According to the data of the FS-3 FS scale (oculomotor disorders), the average indicators were as follows: group I - 1,4 ± 0,3; group II - 1,6 ± 0,3; and according to the severity of visual disturbances, the gradations were as follows: group I: 0 points – 32 (14.8%), 1 point – 30 (13.9%), 2 points – 29 (13.4%), 3 points – 18 (8.3%); group II: 0 points – 16 (7.4%), 1 point – 40 (18.5%), 2 points – 32 (14.8%), 3 points – 19 (8.8%) ***(Table 4)***.

During the clinical and neurological examination, the presence of complaints of diplopia was recorded in 39 (18.1%) patients with MS, blurred vision or its clouding - in 63 (29.2%) patients.

Oculomotor deficiency was also manifested by vertical or horizontal nystagmus - in 117 (54.2%) patients, convergence and accommodation insufficiency - in 125 (57.9%) patients, uncoordinated movements of the eyeballs - in 48 (22.2%) patients, disparity eyeballs vertically (or horizontally) – in 29 (13.4%) patients, saccades – in 72 (33.3%) patients, oscillopsia – in 8 (3.7%) patients, eye dysmetria – in 10 (4.6%) patients, gaze paresis - in 6 (2.8%) patients. In total, oculomotor disorders occurred in 168 (77.8%) patients with multiple sclerosis of both groups, among them in group I - in 77 (35.6%) patients, while in group II - in 91 (42.1%) patients.

The average level of prevalence of neurological symptoms in the patients with multiple sclerosis, caused by dysfunction of other cranial nerves brain stem, was as follows: 129 patients (59.7%).

Involvement of the trigeminal nerve was recorded in 63 patients (29.2%), including paresthesias and/or dysesthesias in the facial area (36 patients, 16.7%), odontogenic facial pain (10 patients, 4.6%), trigeminal neuralgia (7 patients, 3.2%), trigeminal sensory neuropathy (3 patients, 1.4%), arthrogenic facial pain due to temporomandibular joint arthropathy (7 patients, 3.2%).

Facial nerve was involved in 66 patients (30.6%), which included myofascial facial pain (4 patients, 1.9%), xerostomia (dryness in the mouth) (37 patients, 17.1%), facial paresis (29 patients, 13.4%).

We performed an analysis of neurological disorders in the debut of the disease ***(Table 5)***: in 171 (79.2%) patients, the debut of MS was monosymptomatic, and in 45 (20.8%) patients, multifocal symptoms were detected as the first manifestations of the disease.

A predominance of pyramidal motor disorders (in the form of pyramidal insufficiency, central para-, mono-, hemi-, paraparesis of one degree or another) was established in the debut of MS - in 32 (14.8%) patients, visual disorders - in 36 (16.7%), oculomotor disorders - in 47 (21.8%) and polysymptomatic onset of MS - in 45 (20.8%) patients.

Table 4. Analysis of visual and oculomotor disorders in patients with MS according to data from the FS-3 and FS-6 scales by J. Kurtzke

Groups of patients with multiple sclerosis	**Average indicators on the FS-3 and FS-6 scales (mean ± standard deviation)**		**Characteristics of the point assessment of the degree of impaired functional systems FS-3 and FS-6**	
	FS-3 (mean ± SD)	**FS-6 (mean ± SD)**	**FS-3, abs. (%)**	**FS-6, abs. (%)**
group I (n = 109)	1.4 ± 0.3	0.8 ± 0.2	0 points – 32 (14.8)	0 points – 63 (29.2)
			1 point – 30 (13.9)	1 point – 21 (9.7)
			2 points – 29 (13.4)	2 points – 14 (6.5)
			3 points – 18 (8.3)	3 points – 11 (5.1)
group II (n = 107)	1.6 ± 0.3	1.4 ± 0.3	0 points – 16 (7.4)	0 points – 37 (17.1)
			1 point – 40 (18.5)	1 point – 30 (13.9)
			2 points – 32 (14.8)	2 points – 18 (8.3)
			3 points – 19 (8.8)	3 points – 16 (7.4)

Table 5. Analysis of symptoms of debut in patients with MS

Debut symptoms of MS	**Number of patients with MS (abs.,%)**		
	group I (n = 109), abs. (%)	**group II (n=107), abs. (%)**	**Total (n=216), abs. (%)**
Pyramidal disturbances	15(6.9)	17 (7.9)	32 (14.8)
Visual disorders	17 (7.9)	19 (8.8)	36 (16.7)
Oculomotor disorders	22(10.2)	25(11.6)	47 (21.8)
Coordination disorders	4 (1.9)	3 (1.4)	7 (3.2)
Vestibular disorders	3 (1.4)	2 (0.9)	5 (2.3)
Disorders of general sensitivity	5 (2.3)	7 (3.2)	12 (5.6)
Mild facial paresis	7 (3.2)	8 (3.7)	15 (6.9)
Trigeminal neuralgia	-	6 (2.8)	6 (2.8)
Psychoemotional disorders	2 (0.9)	4 (1.9)	6 (2.8)
Pelvic disorders	2 (0.9)	3 (1.4)	5 (2.3)
Polysymptomatic onset	32 (14.8)	13 (6.0)	45 (20.8)

Visual disorders were usually manifested by the clinic of retrobulbar neuritis with a pronounced decrease in visual acuity, disturbances in visual fields and changes in the fundus, and, as a rule, subsequent recovery to one degree or another. In the absolute majority of cases, visual problems were unilateral. In 21 (9.7 %) patients, the onset occurred with damage to other cranial nerves.

Thus, in group I of patients with MS, the disease debuted most frequently with oculomotor disorders, polysymptomatic onset, visual disorders, and pyramidal disorders, while in group II of patients with MS, debut symptoms pyramidal disorders, oculomotor disorders, visual disorders, mild facial paresis.

It should also be noted that in patients of both groups of MS with a remitting course, visual disturbances (23.7%) and polysymptomatic onset (18.8%) were the most frequent in the debut. In patients with a progressive course of MS of both groups, at the onset of the disease, movement disorders were more often observed (27.03%), and to a lesser extent - oculomotor disorders (5.8%) and sensory disorders (5.3%).

Furthermore, it was found that visual and oculomotor symptoms, although responsive to pharmacological treatment—particularly corticosteroid pulse therapy—often leave residual effects. These may include incomplete recovery of visual acuity or visual fields, or persistent symptoms such as facial pain or numbness in the orbital region, even when other exacerbation-related symptoms of MS have fully resolved. The main characteristic feature of MS, described by J. M. Charcot, there is " scattering in time", that is, in the future there is a possibility of new exacerbations of the disease. These exacerbations can include renewed episodes of retrobulbar neuritis, full or partial recurrence of visual disturbances and pain symptoms in the orbit. Taking into account the characteristic features of the course of multiple sclerosis, such as the presence of the syndrome of "instability of clinical manifestations" as a result of adverse environmental influences (primarily, a general or even local increase in temperature: the so-called "hot bath symptom", alimentary factors, etc.), blocking of nerve impulse conduction in partially demyelinated nerve conductors may periodically occur due to shortening of the action potential with the appearance of transient or more persistent symptoms of decreased vision, impaired perception of colors, visual fields defects, orbital pain) even without exacerbation of multiple sclerosis.

It was also possible to show that in older age groups of patients with multiple sclerosis (45 and > years), color perception disorders develop almost twice as often as in younger patients.

When analyzing the correlations between the severity of visual and oculomotor disorders and the FSS, BDI-II, VAS, MSSE and SF-36 indicators, we were able to establish that the closest direct correlations are observed between visual disorders and depression indicators according to the BDI-II (r= 0.28 – group I; r= -0.36 – group II, $p<0.05$) and cognitive functions according to MSSE data (r= 0.21 – group I; r= -0.29 – group II) $p<0.05$), as well as between oculomotor disorders and the degree of fatigue according to FSS data (r= 0.34 – group I; r= -0.56 –group II, $p<0.05$).

Thus, it is clear that the combination of physical, cognitive and psychological symptoms in multiple sclerosis can make a negative contribution to the process of deepening the decrease in the patient's functional activity.

The results of the influence of various types of comorbid pathology in patients with MS on the severity of visual and oculomotor disorders were as follows: the most pronounced visual disorders (in relation to the average of the group II) were observed in patients with gastroenterological comorbidity (1.9±0.4; $p <0.01$) and cerebrovascular comorbidity (2.1 ± 0.5; $p<0.05$); while the most pronounced oculomotor disorders (in relation to the average of the group II) occurred in patients with gastroenterological comorbidity (2.0 ± 0.3; $p<0.05$), and under conditions of polycomorbidity: three concomitant diseases (2.3 ± 0.8; $p<0.05$), four or more concomitant diseases (2.5 ± 0.9; $p<0.05$). Conversely, the least pronounced visual and oculomotor disorders were observed in patients with MS autoimmune comorbidity (1.2±0.3; $p<0.05$).

Considering the fact that special difficulties in stopping visual and oculomotor disorders arise in conditions of comorbidity with MS with diseases of the stomach and hepatobiliary system, cerebrovascular diseases, as well as in conditions of deepening manifestations of fatigue, depression and cognitive disorders, given the frequent residual symptoms of retrobulbar neuritis, the insufficient effectiveness of their drug treatment and stopping of oculomotor disorders, and the possibility of a partial or complete return of the symptoms of exacerbation in the future, it is advisable to use acupuncture methods as part of the complex treatment of MS, in particular, the method of scalp acupuncture with an effect on the areas of the scalp and corporal acupuncture points, capable of enhance the effects of scalp acupuncture.

Discussion

Visual disorders (afferent visual abnormalities) and oculomotor disorders (efferent visual abnormalities) are frequent symptoms in MS patients, and can occur temporarily or permanently, appear parallel to other symptoms of the disease, or independently of them [18, 19, 20, 21, 22].

MS requires complex treatment, both pathogenetic and symptomatic, which is not always sufficiently effective [5, 22, 23, 24]. Although in the case of acute retrobulbar neuritis, courses of pulse therapy with methylprednisolone are often quite effective, sometimes in combination with plasmapheresis, which can accelerate the recovery of vision in approximately 70% of patients [10], the results of treatment of visual disturbances in MS are generally contradictory [5].

In patients with MS with retrobulbar neuritis, even with the condition of complete regression of exacerbation of MS, in the future there is a possibility of a partial return of symptoms of exacerbation (visual, pain) due to incomplete remyelination and negative effects of environmental factors or a new exacerbation [25]. This requires the development of new treatment methods that would have a neuroprotective effect and would be able to restore impaired functions in patients with MS [5, 25, 26]. One of these methods is scalp acupuncture, which is advisable to use as part of the complex treatment of MS patients with visual and oculomotor disorders and pain of various localization [5, 25, 26]. At the same time, individualized acupuncture treatment is necessary, and

in this case it is advisable to use acupuncture diagnostic methods [27].

Researchers indicate that they want to adapt acupuncture diagnostic methods (in particular, syndromic diagnostic methods of traditional Chinese medicine) to specific lesions in MS and determine algorithms for their diagnosis [4, 5, 19, 27]. There is also an opinion that it is advisable to conduct larger studies to assess the effectiveness of acupuncture diagnostic methods for specific lesions in MS, as well as to study the mechanisms of therapeutic influence of acupuncture methods for specific lesions in MS.

So, in one work [25] it is described that special difficulties in stopping visual disturbances and painful symptoms of the orbital area arose under the conditions of comorbidity of MS with diseases of the stomach and hepatobiliary system. The use of acupuncture techniques based on scalp acupuncture and its potentiation with the help of acupuncture points of regular acupuncture meridians and extra-meridian acupuncture points in a complex of therapeutic measures in patients with visual disturbances and facial pain due to retrobulbar neuritis in MS patients made it possible to better treat the above-mentioned disorders with therapy of exacerbation and stop them if they are residual symptoms of exacerbation or occur outside the exacerbation of MS. Another work [4] deals with the treatment of visual and oculomotor disorders in patients with MS using scalp acupuncture.

Thus, it can be noted that acupuncture treatment is a promising non-medicinal remedy for stopping visual and oculomotor disorders in MS (which should be used in a complex of therapeutic measures).

Conclusions

1. The prevalence of visual disorders of patients with MS was 56.0%, and oculomotor disorders - 85.2%.

2. Oculomotor disorders were more widely represented in patients with MS, which, in our opinion, is associated with damage to the structures of the posterior longitudinal bundle, which is often affected in MS due to the "scattering in space" characteristic of the disease.

3.It was found that in patients with multiple sclerosis visual disorders were most clearly correlated with the level of depression and cognitive impairment. Oculomotor disorders in patients with MS were most clearly correlated with levels of fatigue.

4. In the group of patients with MS with comorbid pathology, visual and oculomotor disorders were significantly more prevalent.

Disclosure

Conflict of Interest

The authors declare no conflict of interest.

Ethical Standards

All procedures performed on patients during the study adhered to the ethical standards of the institutional and national ethics committees, as well as the 1964 Helsinki Declaration and its subsequent amendments or comparable ethical standards.

Informed Consent

Written informed consent was obtained from all patients.

Funding

No funding was received for this research.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):37-43
doi: 10.25305/unj.318996

Transforaminal endoscopic microdiscectomy in the treatment of patients with herniated intervertebral discs in the lumbar spine

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Received: 25 December 2024
Accepted: 17 February 2025

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More than 800,000 microdiscectomies are performed annually worldwide. According to various authors, good and excellent results are about 85%, with adequate selection of patients for surgical treatment. Nevertheless, up to 40% of patients continue to suffer from pain, motor and sensory disorders, although their intensity decreases after surgery. Therefore, the search for new methods of surgical interventions that will improve the results of treatment of such patients continues.

In the late 90s of the last century, the JOIMAX company (Germany) developed a technique for endoscopic transforaminal microdiscectomy, which used a lateral (transforaminal) rather than a standard interlaminar approach. According to literature data, endoscopic transforaminal microdiscectomy has up to 93% of positive outcomes.

Objective. To study the immediate and long-term outcomes of treatment of patients with herniated intervertebral discs in the lumbar spine using the transforaminal endoscopic microdiscectomy method.

Materials and methods. The immediate (1st day after surgery) and long-term (6th month postoperatively) outcomes of surgical treatment of 68 patients with herniated intervertebral discs in the lumbar spine were studied. Patients were operated on using the endoscopic transforaminal microdiscectomy method at the «Family Medicine Clinic», Dnipro from 2020 to 2024.

Results. There were 52 men and 16 women, the age of the patients ranged from 24 to 68 years (average 44.2 years), the duration of the disease was from 6 months to 12 years. Before the operation, the average pain score according to VAS was 8.7 points. Pain syndrome on the VAS scale on the 1st day after surgery was, on average, 3.5 points, after 6 months - 3 points. After 6 months after surgery, 63 patients (93%) had good treatment outcomes according to the J. MacNab scale. Unsatisfactory results were in 5 patients (7%).

Conclusions. Transforaminal endoscopic microdiscectomy is a modern highly effective minimally invasive method of surgical treatment of herniated intervertebral discs in the lumbar spine, which allows to significantly reduce intraoperative trauma, the patient's hospital stay, accelerate the rehabilitation of patients, and improve treatment outcomes.

Keywords: *transforaminal endoscopic microdiscectomy; minimally invasive treatment methods; outpatient neurosurgery*

Introduction

It is estimated that more than 800,000 microdiscectomies are performed annually worldwide [1]. According to various authors, the rate of good to excellent outcomes reaches approximately 85% when patients are appropriately selected for surgical treatment; however, around 40% of patients continue to experience pain, motor, and sensory disturbances, albeit with reduced intensity postoperatively [1, 2, 4]. Unsatisfactory treatment outcomes are classified under the so-called "failed back surgery syndrome" (FBSS). Postoperative compressive scar-adhesive epiduritis—a reactive productive inflammatory process that invariably develops after surgical interventions (including microdiscectomies)—accounts for about 25% of FBSS cases [2]. According to different sources, FBSS is responsible for approximately 20% of repeat surgeries. Although microdiscectomy continues to be considered the gold standard, over the past 30 years, numerous new techniques and their modifications have been proposed. The developers of these methods aim to minimize the trauma associated with surgical access while maintaining the radical nature of the operation [1, 2]. The ongoing search for new surgical techniques focuses on reducing intraoperative trauma, shortening hospital stays, decreasing the frequency of postoperative complications, improving treatment outcomes, accelerating patient rehabilitation, and lowering treatment costs.

The predominant trend is the enhancement of the micro-surgical interlaminar approach, particularly

through the development of retractors that minimize damage to the paravertebral muscles. Additionally, minimally invasive approaches to herniated discs have been proposed that avoid the removal of the ligamentum flavum and additional facetectomy [3–7]. A major drawback of the posterior interlaminar approach is that, after incision or resection of the ligamentum flavum, the surgeon sees the nerve root and dural sac in the wound, while the herniation is typically located posterior to these structures; thus, its removal requires traction of both the nerve root and the dural sac [5, 8–11]. Alongside advancements in microsurgical techniques, endoscopic methods have been introduced to reduce access-related trauma. The most widely used method in the 1990s was endoscopic monoportal or biportal nucleotomy, which was successfully applied not only in the treatment of disc protrusions and small hernias but also in sequestrated herniations [4–9]. However, this method lacked the versatility of microdiscectomy and often necessitated repeat surgical interventions.

At the end of the 1990s, the German company "Joimax" developed a technique for endoscopic microdiscectomy that used a lateral (transforaminal) approach instead of the standard interlaminar one. In this procedure, the surgeon enters the spinal canal laterally through the intervertebral foramen. This allows for the herniated disc to be visualized first, followed by the nerve root. With this approach, nerve root traction is not required. The TESSYS (Transforaminal Endoscopic Surgical System) technique has gained widespread adoption across Europe [7–11]. The instruments used in this procedure are continually being refined, thereby expanding the capabilities of the technique. Numerous studies by international authors indicate the high efficacy of endoscopic transforaminal microdiscectomy and a low incidence of failures and complications. According to published data, endoscopic transforaminal microdiscectomy achieves approximately 93% positive outcomes, which is comparable to the efficacy of traditional "open" microdiscectomy [10–17]. Endoscopic transforaminal microdiscectomy offers several important advantages: the skin incision is only 5 mm long and typically heals without any cosmetic defect; muscles and aponeuroses are not incised but rather gently separated using tubular dilators; the maximum port diameter is 7.5 mm; and the absence of oxygen exposure reduces the risk of postoperative compressive scar-adhesive epiduritis. Hospitalization time does not exceed 12–20 hours, and the patient is mobilized three hours after surgery. These features qualify the technique as a form of "ambulatory neurosurgery", as a significant number of patients are discharged on the same day the operation is performed. The rehabilitation period is three times shorter than that following conventional microdiscectomy. However, some authors argue that the method is insufficiently radical and not universally applicable [11–15, 19].

Objective: To investigate the short- and long-term outcomes of treating patients with lumbar intervertebral disc herniation using transforaminal endoscopic microdiscectomy.

Materials and Methods

Study design

A single-center retrospective and prospective controlled study was conducted involving 68 patients. The medical records of 52 patients who underwent transforaminal endoscopic microdiscectomy between 2020 and 2024 were analyzed. The prospective arm of the study, comprising 16 patients, was conducted in 2024.

Study participants

The participants were patients with lumbar intervertebral disc herniations who underwent surgery at the "Family Medicine Clinic" (Dnipro, Ukraine).

The study was approved by the Biomedical Ethics Committee of Kherson State University (Minutes No. 7 dated June 30, 2024).

Inclusion Criteria

Patients with foraminal, posterolateral, or paramedian herniations in the lumbar spine who had completed a 4-week course of conservative therapy without positive effect.

Exclusion Criteria

Pre-defined limitations of the method included central disc herniations, foraminal stenosis, nerve root exit through the inferior aspect of the foramen, cranial migration of L5-S1 herniation, and life-threatening contraindications.

Analyzed parameters

Sex and age of the patient, duration of the disease, level, size, and location of the herniation, evaluation of outcomes using the Visual Analog Scale (VAS) and the modified J. MacNab scale.

Surgical technique

The procedure was performed under intravenous anesthesia with local potentiation. Muscle relaxant solutions were not used, which is essential for this type of surgery. The patient was placed in a prone position. The level of surgical intervention was verified using intraoperative radiography. The surgical approach is crucial to the success of the procedure; depending on the level of intervention, the distance from the midline increases in the caudal direction ***(Fig. 1)***. The operation can be conventionally divided into three stages:

a) Entry point – determined using specific anatomical landmarks ***(Fig. 2)***;

b) Surgical access – achieved using dilators and reamers, followed by placement of the endoscopic port ***(Fig. 3 and 4)*** into Kambin's triangle;

c) Main stage – herniation removal – the assistant or surgical nurse monitors the muscles of the corresponding myotome (beginning from the stage of foraminal opening expansion), which prevents nerve root injury, as any compression is immediately indicated by muscle twitching. Therefore, muscle relaxants are not used.

After the operation is completed, one or two sutures are applied to the skin.

Statistical analysis

Statistical processing of the research data was performed using Python v3.9.5 (https://www.python.org/downloads) in the JupyterLab development environment (https://jupyter.org/install). Comparisons between independent groups were conducted using Fisher's exact test. The error threshold was set at $p <$

This article contains some figures that are displayed in color online but in black and white in the print edition.

Fig. 1. Indentation from the midline depending on the level of intervention

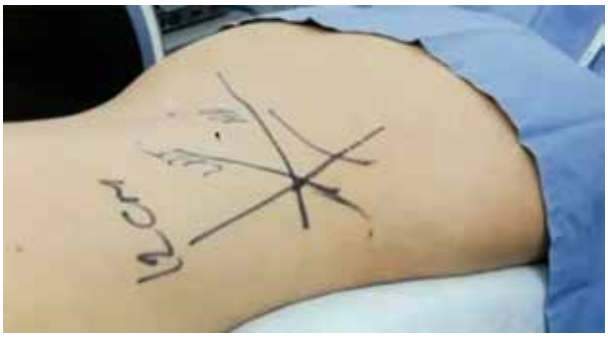

Fig. 2. Entry point for endoscope port placement

Fig. 3. Endoscope port placement

Fig. 4. Endoscope photo

0.0001. A value of $p < 0.0001$ was considered critically significant for all types of analysis performed.

Results and discussion

Patient characteristics

The short-term (first postoperative day) and long-term (6 months after surgery) outcomes of surgical treatment were studied in 68 patients with lumbar intervertebral disc herniation. The patient was examined either upon discharge from the hospital or during wound dressing (for those discharged on the day of surgery), and again during a scheduled follow-up consultation six months later. Surgical outcomes were evaluated using the VAS and the modified J. MacNab scale. This methodology is routinely used at the "Family Medicine Clinic" (Dnipro) for the removal of paramedian, posterolateral, and foraminal hernias in the lumbar spine.

Among the patients, there were 52 men and 16 women aged 24 to 68 years (mean age – 44.2 years). The duration of the disease ranged from 6 months to 12 years. In all cases, conservative treatment methods, including physiotherapy and sanatorium-resort therapy for a period of no less than 4 weeks, failed to yield the desired results. All patients underwent magnetic resonance imaging (MRI) during the preoperative period.

Indications for surgical intervention included persistent lumbosciatic syndrome, sensory disturbances, moderate to severe motor deficits, and reflex

impairments, combined with ineffective conservative therapy lasting at least 4 weeks and confirmed by morphological signs such as MRI-proven disc herniation. Surgical interventions were performed in the presence of neurocompressive syndromes caused by paramedian, posterolateral, or foraminal hernias (median hernias and L5–S1 hernias with cranial migration were removed as previously described).

The size of the foraminal opening and the location where the nerve root exits through it ***(Fig. 5)*** [18] are of crucial importance. To enlarge the foramen and place the endoscopic port, it is necessary to preserve the anatomical structure of the foraminal opening. If the nerve root exits through its upper portion, and the lower part, even in the presence of stenosis, still has space for placing a guidewire, the intervention can be successfully performed. However, if the root exits through the lower portion of the foramen or there is significant stenosis due to spondyloarthrosis, developmental anomalies, or pronounced spondylolisthesis, the operation will be unsuccessful—except in cases of foraminal hernias, where foramen opening is not required.

Herniated discs at the L2–L3 level were detected in 5 patients (7%), at L3–L4 in 2 patients (3%), at L4–L5 in 35 patients (52%), and at L5–S1 in 26 patients (38%). Paramedian hernias were diagnosed in 21 cases (31%), posterolateral in - 39 cases (57%), and foraminal - in 8 cases (12%) ***(Table 1)***.

According to MRI data, in 32 cases (47%) the hernias measured up to 8 mm, while in 36 cases (53%) they exceeded 8 mm.

Treatment outcomes

Before surgery, the average pain score on the VAS was 8.7 points. On the first day after surgery, it decreased to 3.5 points, and six months later, it was 3.0 points ($p < 0.0001$ compared to the preoperative score).

Six months after the surgical intervention, 63 patients (93%) demonstrated good or satisfactory treatment outcomes according to the J. MacNab scale, while 5 patients (7%) had unsatisfactory results ***(Table 2)***.

Clinical Case

Patient H., a 53-year-old female, was hospitalized at the "Family Medicine Clinic" Medical Center on May 27, 2024, with the diagnosis of a posterolateral intervertebral disc herniation at the L4-L5 level with a foraminal component, L5 right-sided radiculopathy, and pronounced pain and muscle-tonic syndromes.

Upon admission, the patient complained of intense lower back pain radiating along the lateral surface of the right lower limb.

She has been suffering from this condition for several years; however, during the last month, the pain syndrome significantly worsened (9 points on the VAS). She associates the onset of the condition with the physical nature of her occupational activities.

She previously underwent conservative treatment involving physiotherapeutic procedures and sanatorium-resort therapy. However, during the last three weeks, despite the treatment, the pain in her leg intensified markedly.

Objective examination revealed pronounced tenderness upon palpation of the spinous processes of the L4 and L5 vertebrae, hypoesthesia along the L5 dermatome on the right, and a sharply positive Lasegue's sign on the right.

MRI revealed a posterolateral intervertebral disc herniation at L4-L5 with a right-sided foraminal component and severe compression of the right L5 nerve root ***(Fig. 6)***.

A transforaminal endoscopic microdiscectomy of the L4-L5 intervertebral disc on the right was performed. ***Fig. 7*** shows fluoroscopic guidance of the endoscope port placement in the specified area of the L4-L5 intervertebral space on the right.

Immediately after the surgery, the patient reported complete regression of the pain syndrome. She was mobilized 3 hours postoperatively. Since she resides in another city, she remained in the hospital overnight. She was discharged the following morning in satisfactory condition. Two weeks later, she reported feeling well, with no complaints and a postoperative scar showing no signs of inflammation ***(Fig. 8)***. One and a half weeks after surgery, the patient resumed her regular professional activities.

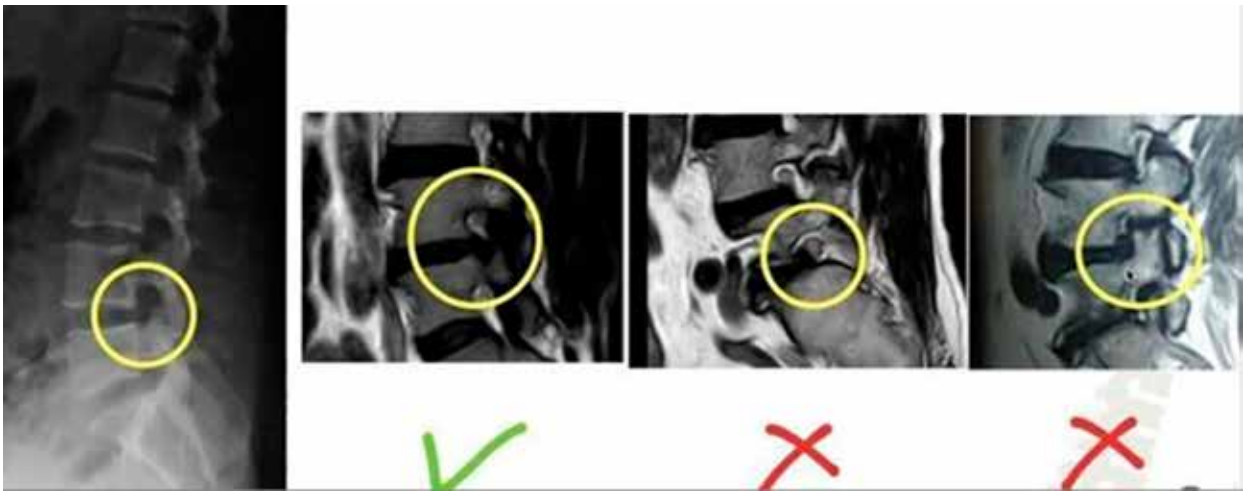

Fig. 5. Possibility of intervention depending on the size of the foraminal opening and the location of the nerve root (https://doi.org/10.1002/ca.22286)

Table 1. Distribution of cases according to type and level of herniation

Level	Type of hernia			Total
	Paramedian	Posterolateral	Foraminal	
L2-L3	0	2 (3,0%)	3 (4,0%)	5 (7,0%)
L3-L4	0	1 (1,5%)	1 (1,5%)	2 (3,0%)
L4-L5	12 (18,0%)	21 (31,0%)	2 (3,0%)	35 (52,0%)
L5-S1	9 (13,0%)	15 (22,0%)	2 (3,0%)	26 (38,0%)

Table 2. Evaluation of treatment outcomes using the J. MacNab scale six months after surgery

Results	Number of observations	
	Abs.	%
Good	51*	75
Satisfactory	12	18
Unsatisfactory	5	7
Total	68	100

Note. * – The difference is statistically significant ($p < 0.0001$) compared to the indicator in patients with an unsatisfactory outcome.

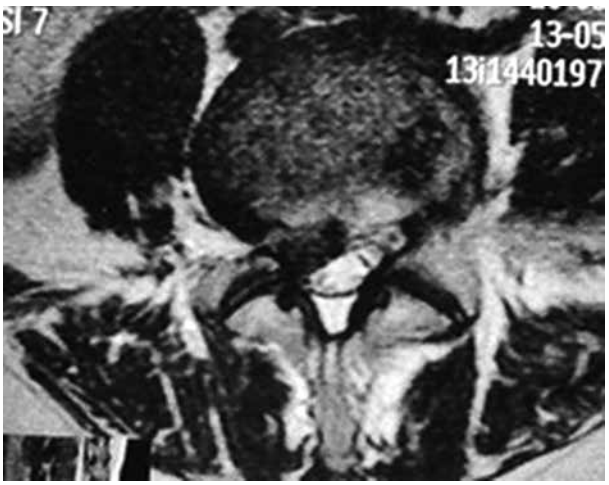

Рис. 6. MRT scan. Posterolateral herniation of the L4-L5 intervertebral disc with a right foraminal component

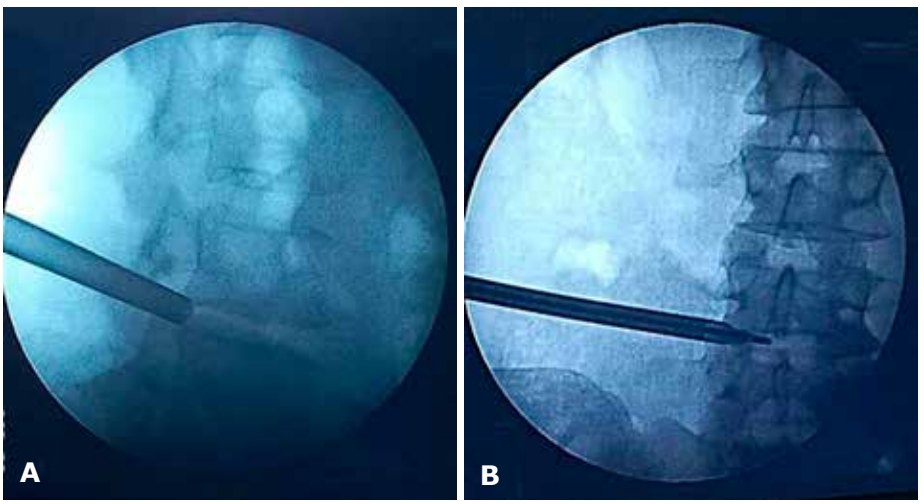

Fig. 7. Port placement: A – lateral projection; B – straight projection

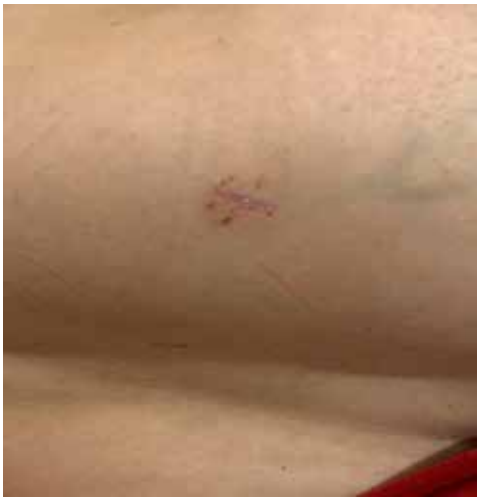

Fig. 8. Postoperative scar two weeks after surgery

Discussion

X. Tao et al. (2018) [19] conducted a randomized study assessing treatment outcomes in 462 patients (231 patients in the traditional microdiscectomy group and 231 in the endoscopic transforaminal microdiscectomy group), using the VAS and the modified J. MacNab scale at 1 day, 1 month, 3 months, and 6 months postoperatively. It was found that the TESSYS technique significantly reduces the duration of surgery, intraoperative blood loss, surgical trauma, and length of hospital stay, while accelerating rehabilitation and improving treatment outcomes. The rate of good results according to the modified J. MacNab scale was 87.88% with TESSYS and 84.85% with traditional microdiscectomy.

According to Shenghua He et al. (2018), the success rate with TESSYS reached 98% one year after surgery [20]; data from Chao Yuan et al. (2020) [21] indicate a success rate of 95%.

Future research prospects

TESSYS is a modern, highly effective, minimally invasive technique for the removal of lumbar intervertebral disc herniations. Like other surgical methods, it has its advantages and disadvantages. The primary advantage is its minimally invasive nature combined with adequate radicality when compared to traditional microdiscectomy. However, a notable disadvantage is its insufficient universality.

According to the author, future research should focus on improving the visualization of herniated discs and the planning of interventions — in particular through the use of artificial intelligence. This is especially relevant for determining the entry point, which is currently calculated in a highly subjective manner and may contribute to unsuccessful surgical outcomes. Additional research should address the "safe" placement of the endoscope port along an optimal trajectory to avoid damage to neural and vascular structures, ensure complete herniation removal, and achieve full decompression of the compressed nerve root and/or dural sac.

Conclusions

1. Transforaminal endoscopic microdiscectomy is a modern, highly effective, minimally invasive surgical method for the treatment of lumbar intervertebral disc herniations.

2. Transforaminal endoscopic microdiscectomy enables positive outcomes in 93% of cases.

3. According to various authors, the TESSYS technique significantly reduces intraoperative trauma, intraoperative blood loss, length of hospital stay, accelerates rehabilitation, and improves treatment outcomes.

Disclosure

Conflict of interest

The author declares no conflict of interest.

Ethical standards

All procedures performed on patients during the study complied with the ethical standards of the institutional and national research ethics committees and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from each individual patient.

Funding

This study received no financial support or sponsorship.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):44-54
doi: 10.25305/unj.323331

Outcome of gamma knife radiosurgery in intracranial arterio-venous malformations: A single institution experience

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Received: 20 February 2025
Accepted: 19 March 2025

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Introduction: Gamma Knife radiosurgery (GKRS) provides in general a high dose ionizing radiation to specific target location, which has already been defined by stereotaxy for the treatment.

Arteriovenous malformations (AVMs) are one such indication for GKRS they are rare, occurring at an incidence of 15-18 cases per 100,000 adults, with a rupture rate of 2–4%. GKRS is indicated for small (< 3.5 cm), surgically high-risk, deep-seated and complex AVMs. Successful AVM treatment in GKRS eliminates the risk of intracranial haemorrhage, complete nidal obliteration, limiting the development of new deficit from radiation-induced changes.

Materials and Methods: This study was conducted in the Department of Neurosurgery, a tertiary care center , New Delhi for the duration of two years (September 2019 to September 2021). A total of 40 patients (N) were studied. Variables included demographic profile, clinical profile, AVM grading, radiation dose and treatment outcomes particularly nidal obliteration and symptom resolution. The factors which affected obliteration of AVM and six-monthly follow-up were analysed.

Results: The study showed among all variables that the initial volume of nidus, duration following GKRS were important predictors for AVM obliteration with statistically significant p-values (<0.05).

Conclusion: GKRS is effective treatment modality in AVMs, especially those with low nidus volume, low Spetzler-Martin (SM) grade, deep venous drainage, young age and deep-seated lesions. However, in this study, the p-values were not statistically significant (p-value >0.05) for above parameters. Among all, the initial nidus volume, and the duration of post GKRS for the obliteration of AVM had significant p-values (<0.05).

Key words: *arteriovenous malformations; nidus volume; Gamma Knife Radiosurgery*

Introduction

Gamma Knife radio surgery (GKRS) delivers in general high dose ionizing radiation to specific target location, which has already been defined by stereotaxy for the treatment [1]. Arteriovenous malformations (AVMs) are one such indication for GKRS, they are rare, occurring 15-18 cases per 100,000 adults, with a rupture rate of 2–4% [2]. Vascular malformations are localized collection of abnormal blood vessels having altered blood flow [2]. Clinical presentations include haemorrhage, headaches, seizures, or stroke. AVM are fistulous connections between arteries and veins without capillary involvement with base directed towards meninges and the apex towards ventricular system [3]. There is direct transmission of arterial pressure to venous structures causing increased blood flow, dilation, and vessel tortuosity [4].

Incidence of AVM is at 1.12 to 1.34 per 100,000 individuals or 0.1% of population harbour AVM. Both sexes are affected equally. Annual risk of spontaneous intracerebral hemorrhage (ICH) is 2-4%. Only 12% of AVMs become symptomatic during life with combined annual morbidity and mortality rate of 1%. The cerebral AVMs are seen in 1.4% to 4.3% of autopsies [5, 6, 7, 8, 9].

Treatment modalities for symptomatic AVMs includes surgery, embolization and GKRS. The drawback of GKRS is latency period (2 years). The effectiveness of GKRS depends on location and size of the lesion. GKRS is a well-established treatment modality for cerebral arteriovenous malformations (AVMs), offering high obliteration rates with relatively low morbidity. [10]. Successful AVM treatment with Gamma Knife radiosurgery eliminates the risk of intracranial haemorrhage, complete nidal obliteration, limiting the development of new deficit from radiation-induced changes [11].

Florez-Perdomo et al., (2024) evaluated the safety and effectiveness of GKRS for paediatric AVMs, reporting a 71.64% complete obliteration rate and a low mortality rate of 0.75% [12]. Complications are rebleed and partial obliteration. Dose requirements are determined by location and the size often using the Spetzler-Martin (SM) grading of AVM. [6, 13].

Myeong et al. (2024) demonstrated that time-staged GKRS is a feasible approach for managing large AVMs, achieving satisfactory obliteration rates with acceptable complications [14].

The objective of the present study aims to evaluate the clinical and radiological outcomes of GKRS in AVM management, focusing on nidus obliteration, symptom resolution, and predictive factors such as AVM volume, Spetzler-Martin grade, and radiation dose. It also examines the latency period for obliteration and potential complications.

Materials and Methods

Study Participants

This study was conducted in the Department of Neurosurgery, a tertiary care centre, New Delhi, for the duration of two years (September 2019 to September 2021) to evaluate the outcomes of Gamma knife radiosurgery (GKRS) in patients with intracranial AVM. The Department is a tertiary neurosurgery centre with a dedicated GKRS unit. A total of 40 patients (N) were studied.

Ethical clearance was obtained, and informed consent was secured from all participants.

Inclusion Criteria

Patients with clinical and radiological diagnoses of intracranial AVM who were treated with GKRS were included in the study.

Exclusion Criteria

Exclusion Criteria included other structural abnormalities in addition to AVMs, patient's unwillingness to participate in the study and patient's unwillingness to undergo GKRS for intracranial AVMs.

Study Design

This was a non-randomized retrospective cum prospective observational study.

The primary outcome was AVM nidus obliteration following GKRS. Secondary outcomes included demographic factors (age, sex), clinical presentation (symptoms, neurological deficits), AVM characteristics (nidus volume, Spetzler-Martin grade, location, venous drainage), radiation dose delivered, and treatment-related complications. Imaging included CT and CT Angiography, MRI and MR Angiography with digital subtraction angiography (DSA). For GKRS, Leksell Gamma knife (LKG) model 4C (Elekta, Sweden) was used ***(Fig. 1)***.

The AVM volumes were estimated by using the formulas V = 0.513× (AP×ML×CC) + 0.047 and V = 0.444 × (AP× ML×CC) + 0.339) for diameters in the range 0–2.5cc and 2.5–36cc respectively with a bias of 0.0005cc and 0.007cc respectively [15].

Selection bias was minimized by including all eligible patients treated during the study period, while measurement bias was reduced through standardized imaging protocols and independent assessments by a multidisciplinary GKRS team, including neurosurgeons, radiation oncologists, neurointerventional radiologists, and medical physicists. Decision for appropriateness of GKRS was carried out on case-to-case basis keeping the institutional policy guidelines. The study included 40 patients, based on available cases over the two-year study period.

Quantitative variables including age, nidus volume, radiation dose, percentage of nidus obliteration and follow-up duration, were expressed as mean ± standard deviation (SD), while categorical variables, such as

Fig. 1. Elekta Icon Gamma Knife machine installed at our center

This article contains some figures that are displayed in color online but in black and white in the print edition.

gender, symptoms, AVM location, venous drainage, and Spetzler-Martin grade, were presented as absolute numbers and percentages.

Fig. 2, 3, 4, 5 are the representative images of the patients, showing the AVM, its localisation and planning for purely descriptive purpose only.

Table 1 is the SM grades under which the patients of AVM were classified.

Statistical analysis

Comparisons of means were conducted using the independent Student's t-test for continuous variables, while categorical variables were analysed using the Chi-square test and ANOVA for subgroup comparisons. A p-value of <0.05 was considered statistically significant, and all analyses were performed using SPSS version 24.0.

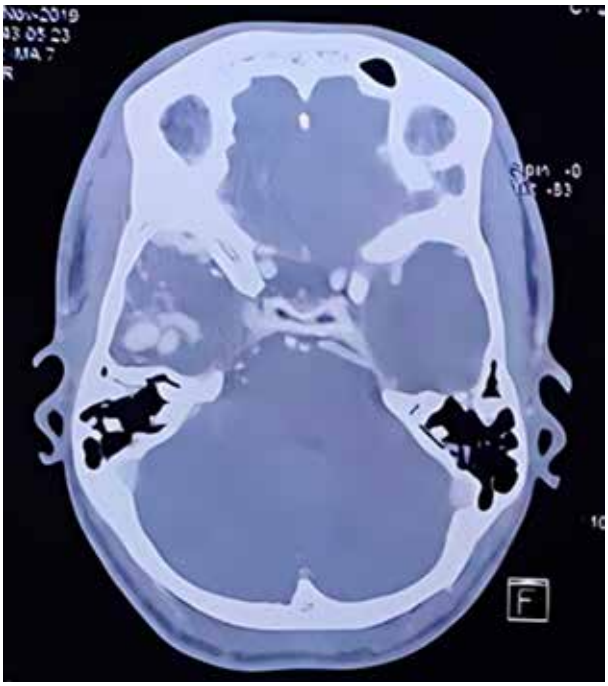

Fig. 2. CT angiogram cerebral vessels showing AVM in the Right temporal region

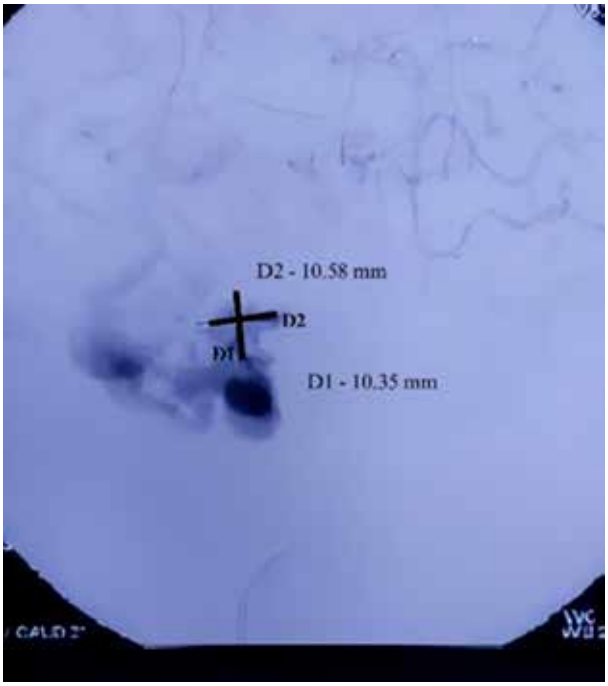

Fig. 3. Digital subtraction angiogram of the left anterior oblique view showing AVM in the Right temporal region with the nidus dimension of 10.35 mm (D1) and 10.58 mm (D2)

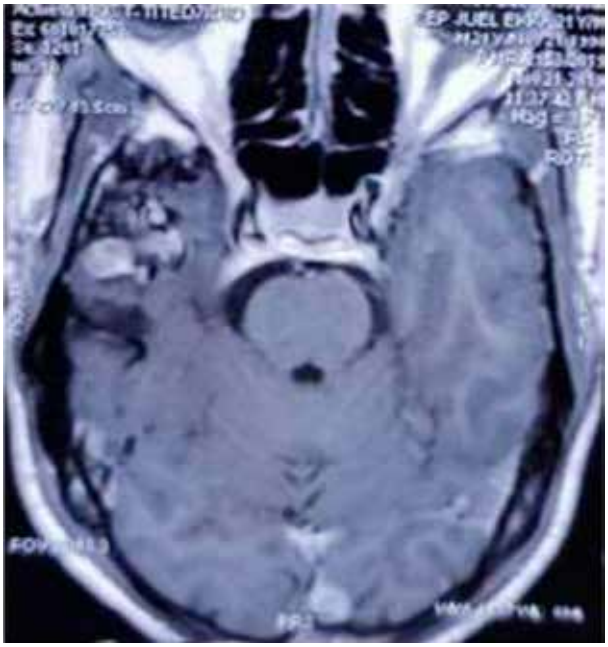

Fig. 4. MRI Brain axial view showing AVM in the Right temporal region

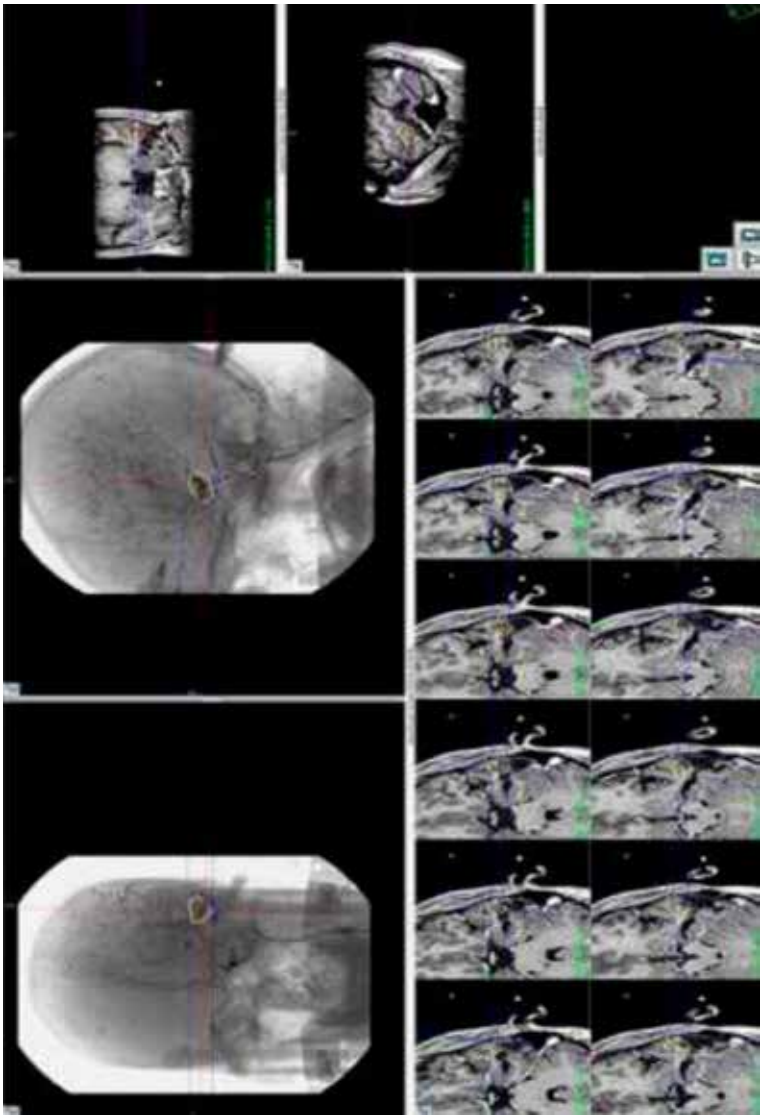

Fig. 5. Representative image showing I Gamma Knife Planning for Left temporal AVM Management

Table 1. Spetzler–Martin Grading System for Brain AVMs

Size of Nidus	Points	Eloquence of adjacent brain tissue	Points	Pattern of venous drainage	Points
Small (<3cm)	1	No	0	Superficial	0
Medium (3-6 cm)	2	Yes	1	Deep	1
Large (> 6cm)	3	-	-	-	-

Note.

Eloquent Brain includes the sensorimotor cortex, language/visual cortex, hypothalamus, thalamus, internal capsule, brainstem, cerebral peduncles, and deep cerebellar nuclei.

Venous Drainage: Superficial if via cortical veins, Deep if involving internal cerebral veins, basal veins, or the precentral cerebellar vein.

Results

In demographic profile of the patients, the male predominance was seen with age group 20 - 40 years. Hemorrhage was initial presentation. Most AVMs were located supratentorially predominantly in lobar regions. A majority of the patients had superficial venous drainage and belonged to SM grade 2, with 87.5% of those patients having complete nidus volume reduction seen after 24 months. The mean duration of follow up was 26.4 months.

Table 2 is complete demographic and clinical profile of the patients with AVM characteristics and the treatment outcome.

Six monthly clinical and radiological assessment was done for a period of 24 months and beyond. Individual variables were studied using test of significance to look for correlation between the variable studied and percentage obliteration of AVM after 24 months. After 24 months of follow-up, our study showed, 100% nidus volume reduction in 34 cases (85%), 75 - 99 % nidus reduction in 5 cases (12.5%), and no nidus volume reduction was seen in 1 case (2.5%) ***(Table 3)***.

On applying paired t-test, to look for the interval change in volume during the follow-up period, the mean change in the volume of the nidus at different points of follow-up that is 06 months, 12 months, 18 months, 24 months and >24 months increases with the duration of follow up and is statistically significant (p-value <0.05) for all durations ***(Table 4)***.

Individual variables were studied using test of significance to look for correlation between the study variable and percentage obliteration >24 months. The results are as under ***(Table 5)***.

The obliteration percentage was higher in younger age (< 40 years), on applying Chi square test to analyse the effect of age on obliteration percentage the p-value was 0.777, which was not significant. The percentage obliteration in patients presented with bleed and seizure was 85.3% and 83.3%, respectively p-value was 0.901, not significant. The percentage of obliteration of AVM nidus was 100% in cerebellar and deep-seated AVM as compared to the lobar AVMs (78.5%), the difference was not statistically significant (p-value 0.220). Percentage obliteration is higher in AVMs having deep venous drainage than superficial venous drainage (88.8% vs 76.9%). The difference was statistically not significant (p-value 0.320). The percentage obliteration of AVM nidus is higher in lower SM grade AVM (100% in SM grade 1 and 87.5% in SM grade 2) as compared to SM grade 3 (71.4%) after 24 months. The difference was not statistically significant (p value= 0.510). At 24 months post GKRS, the lower volume of AVM (<4cc) showed higher percentage of obliteration than those with higher nidus volume (>4cc) that is 96.2% vs 61.5%. The difference in the percentage obliteration was statistically significant (p-value = 0.003). This means that small nidus volume (< 4cc) is having a better obliteration rate than large nidus volume (>4cc) and the p-value is statistically significant. Notably, 100% of cases having nidus volume <1cc showed complete obliteration. In the present study it is seen that, with the increase in duration of follow-up, there is gradual increase in the percentage of obliteration of AVM nidus and decrease in the mean nidus volume. On applying paired t-test, to look for the interval change in volume during the follow-up period, the mean change in the volume of the nidus at different points of follow-up that is 06 months, 12 months, 18 months, 24 months and >24 months increases with the duration of follow up and is statistically significant (p-value <0.05) for all durations.

After 24 months of follow up, there was significant improvement in various symptoms except focal neurological deficits which persisted even after the procedure with some improvement in the grade of the deficits.

Kaplan Meier graph was plotted to look for the actual obliteration rates. It was found that the obliteration rate of 32.4%, 57.02%, 77.90%, 93.09% and 97.10% at6, 12, 18, 24 and >24 months respectively**.** Though the mean volume of obliteration increased with time during each point of follow-up, however on comparing between the groups using ANOVA test, the results were statistically not significant.

The rate of obliteration or volume reduction of AVM nidus follows a steep curve till about two years and then gradually attains a plateau. Thus, it may be inferred that to attain an optimal and desired rate of obliteration of AVM nidus, minimum duration of 2 years should be considered and the patients counselled accordingly. If the response is not achieved till 2 years post procedure, alternate procedure or redo gamma knife can be considered.

Table 2. Clinical & treatment outcomes of AVM patients

Parameters		Value
Age (In Years)	16-71 Years (Mean - 35.4 Years)	SD- 16.114
Gender	Male	26
	Female	14
Presentation	Intracranial bleed	34
	Seizures	06
Symptoms	Headache	36
	Vomiting	28
	Loss of consciousness	13
	Focal neurological deficits	08
AVM Location	Supratentorial lobar	28
	Deep seated	08
	Cerebellum	04
Nidus Volume	6.482cc (Mean)	Range 0.05 - 38.68 cc
Venous Drainage	Superficial	27
	Deep	13
SM Grading	Grade 1	01
	Grade 2	32
	Grade 3	07
	Grade 4 & 5	Nil
Radiation Dose	12 Gy-23 Gy (Mean-18.04)	SD 3.969
Complete Nidus Volume Reduction (> 24 Months)	SM Grade 1	100% (01/01)
	SM Grade 2	87.5% (28/34)
	SM Grade 3	71.4% (05/07)
Complete Obliteration	After 06 months	10% (04/40)
	After 12 months	20% (08/40)
	After 18 months	27.5% (11/40)
	After 24 months	60% (24/40)
	After >24 months	85% (34/40)

Table 3. Volumetric reduction in nidus volume during 6 monthly follow-up period

Follow up Period (Months)	N (40)	Percentage (%)
1. Percentage volumetric reduction in nidus volume after 6 months		
0	24	60
1 –24	00	0
25- 49	01	2.5
50-74	05	12.5
75 –99	06	15
100	04	10
2. Percentage volumetric reduction in nidus volume after 12 months		
0	08	20
1 –24	02	05
25- 49	06	15
50 –74	07	17.5
75 –99	09	22.5
100	08	20
3. Percentage volumetric reduction in nidus volume after 18 months		
0	01	2.5
1 –24	01	2.5
25- 49	03	7.5
50 –74	11	27.5
75 –99	13	32.5
100	11	27.5
4. Percentage volumetric reduction in nidus volume at 24 months		
0	01	2.5
1 –24	00	0
25- 49	01	2.5
50 –74	00	00
75 –99	14	35
100	24	60
5. Percentage volumetric reduction in nidus volume > 24 months		
0	01	2.5
1 –24	00	-
25- 49	00	-
50 –74	00	-
75 –99	05	12.5
100	34	85
6. Complete obliteration of AVM		
6 Months	04	10
12 Months	08	20
18 months	11	27.5
24 months	24	60
> 24months	34	85

Table 4. Paired sample test to determine the significance of duration of follow-up on the decrease in nidus volume

Follow up period (In months)	Mean	SD	t - value	p- value	Result (p< 0.05)
0 month 6 months	6.48 3.33	10.43 5.60	2.64	0.012	Significant
0 month 12 months	6.48 2.10	10.43 4.47	3.18	0.003	Significant
0 month 16 months	6.48 1.30	10.43 4.23	3.47	0.001	Significant
0 month 24 months	6.48 0.97	10.43 4.25	3.64	0.001	Significant
0 month >24 months	6.48 0.71	10.43 4.23	3.70	0.001	Significant

Table 5. Variables and percentage obliteration

Variable	100% obliteration (>24months)	< 100% obliteration (> 24 months)	Total
Age			
<40	24	02	26
>40	10	04	14
Gender			
Male	21	05	26
Female	13	01	14
Presentation			
Bleed	29	05	34
Seizures	05	01	06
Location			
Lobar	22	06	28
Cerebellar	04	-	04
Deep Seated	08	-	08
Venous drainage			
Superficial	10	03	13
Deep	24	03	27
Radiation Dose			
SM 1	01	00	01
SM 2	28	04	32
SM 3	05	02	07
Volume of AVM			
4CC	26	01	27
> 4CC	08	05	13

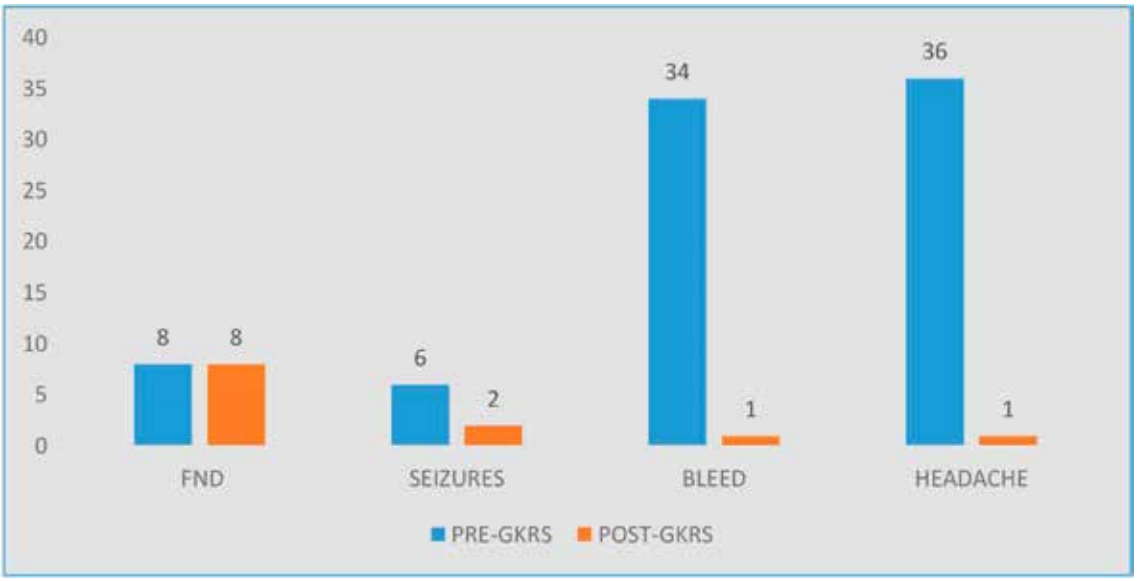

Fig. 6. Clinical assessments after 24 months of follow up

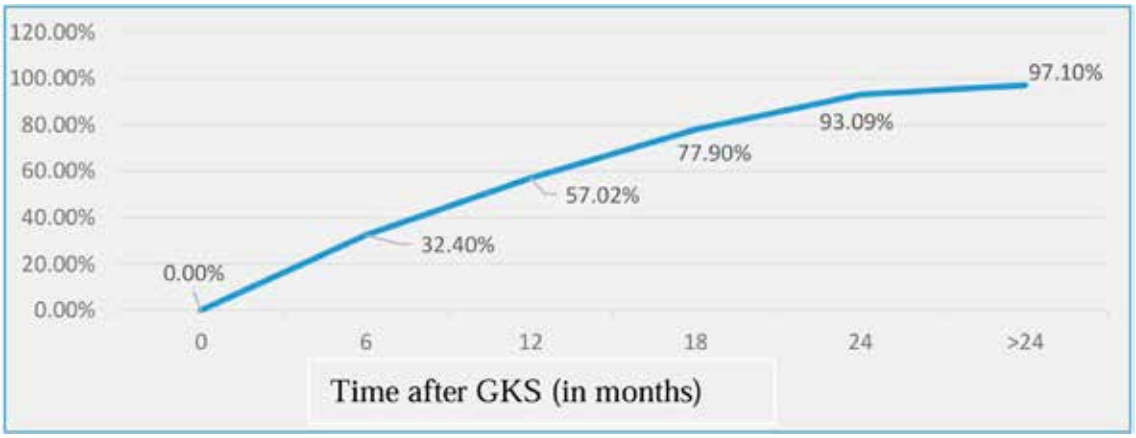

Fig. 7. Kaplan-Meier plot of obliteration over time for total patients included in the study.

Discussion

C Hofmeister, C Stapf, et al [16] found that, the mean age at diagnosis was 31.2 years which corresponded with our study (35.4 years). In our study 35% were females compared to 45%, Deep venous drainage was seen in 67.5% as compared to 55%. AVMs in eloquent locations was found in 20% of cases in our study as compared to 71%. Haemorrhage was seen in 85% of our cases as compared to 53 % and seizures were seen only in 15% in our study as compared to 30%. Headache was seen in 90% of our cases as compared to 14%, neurological deficits were seen in 20% of our cases as compared to 70%.

J Hillman [17] mentioned high-grade AVMs were rare with SM Grades 1 to 3 representing 85% of cases which corresponded with our study. Haemorrhage was the initial manifestation in 69.6% of the cases as compared to 85% of our study.

AVM presents in the age group of 10-40 years with male preponderance [18] which corresponded to our study. The most common presentation was haemorrhage and seizure [19] In our study, haemorrhage was seen in 85% of cases and seizures in 15%. In one study headache was seen in 5-14% [20] [21], in our study, most common symptom was headache (n=36), followed by vomiting (n=28) and loss of consciousness(n=13). Factors predisposing to focal neurological deficits include increasing age, female gender, deep brain location and venous drainage pattern [22] We could not find any such correlation; however, deep seated AVM was predisposing factor for neurological deficits (5 / 8).

Kim B.S. et al [23], Ding D. et al [24] found 90.2% of AVMs were supratentorial in location with deep venous drainage in 24.6% with SM grade 2 or 3 (32.9% each) which corresponded with our study.

Flickinger J.C. et al [25] studied higher radiation dose, deep location, and prior haemorrhage corelated with increased chances of temporary or permanent neurological deficits. In our study, out of the 08 patients who were symptomatic with focal neurological deficits, 05 patients had deeply seated AVM (62.5%) The mean radiation dose given to all the patients who had deficits

was 17.3Gy(>12Gy) and all the patient presented with the history of haemorrhage which correlated with the above study. Of the six patients who presented with seizures, four became seizure-free (66.66%) corresponding to 55.17% found by Heikkinen E.R. et al. [26]

Yang S. Y. et al. [27] showed post GKRS seizure outcome improves in patients with AVM related seizures, provided AVM gets obliterated. In our case, the results were inconsistent. Of the six patients who presented to us with seizures, two patients continued to have seizure even after 100% obliteration of the nidus.

In most series, the obliteration rate following GKRS was > 70% with a range varying from 35% to 92%. Small AVMs had obliteration rate >80% in most series. Time interval between the GKRS and complete obliteration of AVM nidus may range from 1 to 4 years or even longer. The maximum chances of obliteration are during first three years of GKRS.

In our case, the obliteration percentage after 24 months of follow-up was about 85%. Burrow et al. in 2014 [28] studied 80 patients of small AVMs and found the obliteration rate of about 92%, he did not mention the volume of the nidus. In our case, the obliteration rate was in 96% of patients with AVM for nidus volume < 4cc and 62 % obliteration for the nidus volume > 4 cc. Ding et al. [29] studied obliteration rates on 639 cases of ruptured AVMs and achieved an obliteration rate of 67.1% with a mean radiation dose of 21.7 Gy and a mean follow-up of 57.2 months. In our study, the obliteration rate was 85% and a mean dose given was 18.04 Gy with a mean follow-up of 36.4 months.

Thenier et al. [30] reported in a single centre study an overall obliteration rate of 81%. Positive predictors of nidus obliteration included nidus diameter and venous drainage. Ruptured status of AVM had no effect and low-grade AVMs were associated with higher obliteration rates. Similarly, in our study lower SM grade that is SM grade 1 and 2 had a higher percentage obliteration rate (100% and 87.5% respectively) than SM grade 3 (71.4%). Deep venous drainage was related to higher obliteration rate as compared to superficial drainage (88.8% vs 76.9%).

Conclusion

GKRS is an effective treatment for achieving obliteration of brain AVMs. In our study initial volume of nidus and the duration following GKRS are the important predictors for the obliteration of AVM and the p-values came out to be significant (<0.05). Cerebellar and deep seated AVMs had 100% nidus obliteration. SM Grade I had 100% nidus obliteration and Grade II had 87.5% obliteration, however the p -values for the above variable were non-significant. In spite of lack of statistical significance for the above variables the high percentage of obliteration observed in these variables play an important role and are clinically relevant.

The other variables, such as higher prescription dose, deep venous drainage, female gender, and young age although had a high percentage obliteration are also clinically relevant, though the p-values for them were also not significant (p-value >0.05).

Disclosure

Conflict of Interest

The authors declare no conflict of interest.

Informed Consent

Informed consent was obtained from all patients.

Funding

The study received no sponsorship or financial support.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):55-64
doi: 10.25305/unj.322446

Substantiation and development of an optimal method of minimally invasive posterior interbody stabilization of vertebrae using distraction cages in patients with lumbar spondylolisthesis

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Received, 07 February 2025
Accepted, 03 April 2025

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Objective to improve the effectiveness of treatment of patients with lumbar spondylolisthesis, the authors substantiated and developed a novel method of minimally invasive posterior interbody vertebral stabilization (MIPIVS) using distraction cages.

Materials and methods: A clinical prospective comparative (controlled) single-center interventional cross-section study was conducted with a subsequent observation phase, as well as preliminary modeling and development of a novel intervention method. The biomechanical model was used to determine the possibility of restoring the functional state of the spine using distraction cages, and the stress-strain state of the structures was analyzed. The clinical part of the study involved 21 patients aged 35 to 68 (Me=56 [LQ=50; UQ=65]) years (15 women and 6 men), divided into three groups: the study group (n=4) treated with the author's method of MIPIVS (patent application No. a202302383 dated May 18, 2023), a comparison group (n=10) with the standard method of MIPIVS, a control group (n=7) treated with other methods of interbody spondylodesis. Patients were examined according to standard protocols. Logistic and statistical analyses were performed using standard nonparametric methods at a critical level of $p<0.05$. The principles of bioethics and biomedicine were observed.

Results: Before and after surgical treatment of patients with degenerative spondylolisthesis of the lumbar spine, the size of the spinal canal was studied and the dynamics of neurological disorders was assessed. The authors developed a novel method of minimally invasive posterior interbody stabilization of vertebrae using distraction cages and determined the possibility of restoring the value of segmental lordosis, parameters of spinal-pelvic balance and sagittal contour of the spine as indicators of the functional state of the spine using a biomechanical model. The analysis also included assessment of the stress-strain state within the "transpedicular structure – spinal motion segment – distraction cage" system.

Conclusions: The proprietary method of MIPIVS using distraction cages, which has been substantiated and developed, will help to improve the effectiveness of treatment for patients with lumbar spondylolisthesis. Further research prospects include clinical testing of the author's MIPIVS method.

Key words*: spondylolisthesis; treatment; operation; surgery; minimally invasive posterior interbody stabilization of the spine*

Lumbar spondylolisthesis (LS) remains a significant issue in spinal surgery [1–5]. In cases where conservative treatment failed, surgical intervention was typically employed. However, the development of minimally invasive techniques has improved patient management with LS by reducing hospital stays and enhancing rehabilitation outcomes [6–10].

The application of minimally invasive posterior interbody vertebral stabilization (MIPIVS), either as a standalone procedure or using distraction cages, represents a promising approach that aligns with current trends toward preserving normal anatomy and minimizing surgical trauma [11].

The necessity for implementing and refining minimally invasive approaches is driven by numerous global geopolitical crises. The war in Ukraine poses not only a challenge to the national healthcare system but is also associated with a rising incidence of traumatic spinal injuries and multiple post-traumatic and degenerative disorders, including spondylolisthesis [12, 13].

The impact of war extends to healthcare logistics, leading to limited access to medical devices and the need for especially meticulous provisioning during surgical procedures. Preference is given to techniques that achieve the desired clinical outcomes with shorter operation times and lower resource consumption compared to extensive surgical interventions. In this context, the justification and development of effective minimally invasive surgical techniques—such as MIPIVS

with distraction cages ***(Fig. 1)***—constitute a highly relevant objective.

Numerous medical centers are developing and implementing minimally invasive methods of interbody (particularly posterior) vertebral stabilization in cases of LS [14]. Traditional and minimally invasive posterior approaches are commonly used due to their acceptable fusion rates and low complication levels. However, these approaches are limited by the extent of dural and spinal nerve root retraction, and they carry the risk of iatrogenic injury to the paravertebral muscles and disruption of the posterior ligamentous complex. Anterior approaches, which allow bypassing the spinal canal, cauda equina, and spinal nerve roots, are associated with abdominal and vascular complications, while lateral approaches carry a risk of injury to the lumbar plexus and gluteal muscle [15].

Therefore, improving the surgical treatment of spondylolisthesis, particularly through the use of MIPIVS, remains a relevant clinical challenge.

Fig. 1. The Designed distraction cage

Objective: To enhance the effectiveness of treatment for patients with lumbar spondylolisthesis by employing minimally invasive posterior interbody vertebral stabilization using distraction cages.

Materials and methods

Study design

A clinical, prospective, comparative (controlled), single-center cross-sectional interventional study was conducted ***(Fig. 2)***.

Using a biomechanical model with distraction cages, the study assessed the potential for restoring segmental lordosis, spinal-pelvic balance parameters, and sagittal spinal alignment as indicators of spinal functional status. It also analyzed the stress-strain condition within the system "transpedicular construct – spinal motion segment – distraction cage" [16] in the Biomechanics Laboratory of the Sytenko Institute of Spine and Joint Pathology, National Academy of Medical Sciences of Ukraine.

The clinical study included patients with degenerative spondylolisthesis of the lumbar spine and neurocompressive disorders who underwent inpatient treatment in Neurosurgery Department No. 2 between 2017 and 2024, followed by dynamic outpatient monitoring at the clinic of the Municipal Non-Commercial Enterprise of the Kharkiv Regional Council "Regional Clinical Hospital" (Kharkiv).

The research was conducted at the Department of Neurosurgery of Kharkiv National Medical University.

The study complied with the principles of bioethics and biomedicine (ethics and bioethics committee Minutes No. 7 of Kharkiv National Medical University, dated October 10, 2017).

Study Participants

The clinical study involved 21 patients (15 women and 6 men), aged 32 to 68 years (median age – 56 (50; 65) years), divided into three groups: study group (n=4), where the author's technique of MIPIVS was applied (patent application No. a202302383 of 18.05.2023) ***(Fig. 3)***; comparison group (n=10), where the standard MIPIVS technique was used ***(Fig. 4)***; control group (n=7), where other interbody fusion techniques were employed ***(Fig. 5).***

Inclusion Criteria:

- diagnosed degenerative spondylolisthesis of the lumbar spine accompanied by neurocompressive disorders such as neurogenic intermittent claudication, lower limb paresis (3–4 points), and segmental sensory disturbances (L4–L5, L5–S1);
- age range: 32–68 years;
- surgical treatment:

- for the study group: the proposed MIPIVS technique using titanium distraction cages;

- for the comparison group: traditional MIPIVS technique;

- for the control group: alternative methods of lumbar interbody spinal fusion.

Exclusion Criteria:

- Age over 75 years;
- absence of neurological symptoms or neurocompressive disorders such as lower limb paresis (1–2 points) or limb plegia;
- severe somatic and concomitant neurological pathology, vascular disorders of the lower extremities, etc.;
- patient refusal to participate in the study.

Patients were examined according to standard protocols. The type and stage of spondylolisthesis were determined, as well as the degree of sagittal imbalance and associated neurocompressive and biomechanical disorders. This allowed for the calculation of the required intraoperative correction of lordosis to achieve optimal biomechanical compensation, etc.

Following preoperative preparation, minimally invasive surgery was performed using a standard technique with the application of an interbody distraction cage. On the first postoperative day, in the absence of contraindications, patients underwent follow-up radiographic examination to evaluate the extent of correction and calculate key biomechanical parameters (lordosis angle, sacral slope, pelvic tilt variability, and pelvic incidence relative to the sagittal vertical axis).

This article contains some figures that are displayed in color online but in black and white in the print edition.

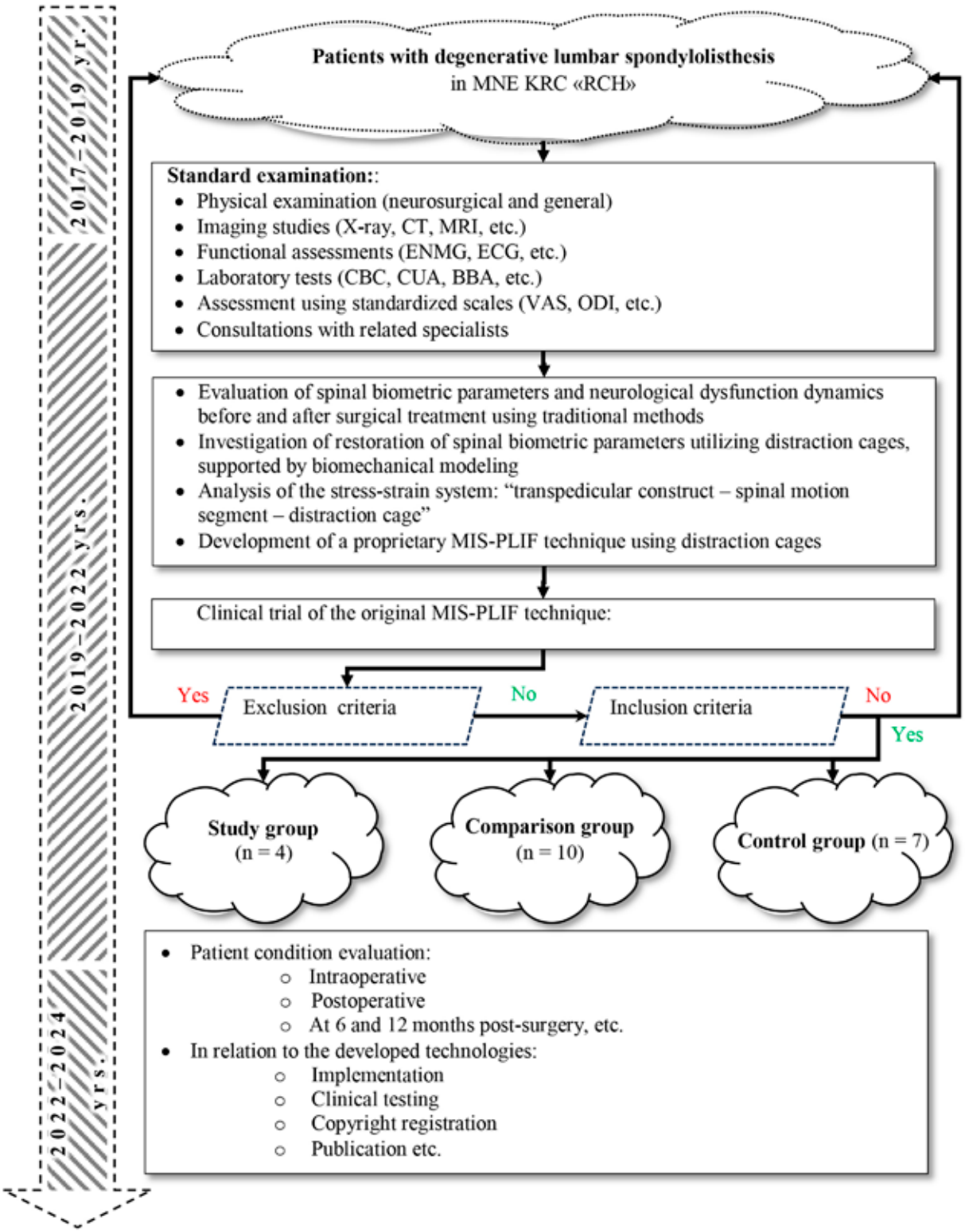

Fig. 2. Study Design:

MNE KRC «RCH»– Municipal Non-Commercial Enterprise of the Kharkiv Regional Council "Regional Clinical Hospital"; CT – computed tomography (X-ray); MRI – magnetic resonance imaging;
ENMG – electroneuromyography; ECG – electrocardiography; CBC – complete blood count; CUA – clinical urinalysis; BBA – biochemical blood analysis; VAS – visual analogue scale;ODI – Oswestry Disability Index; MIS-PLIF – minimally invasive surgery posterior lumbar interbody fusion.

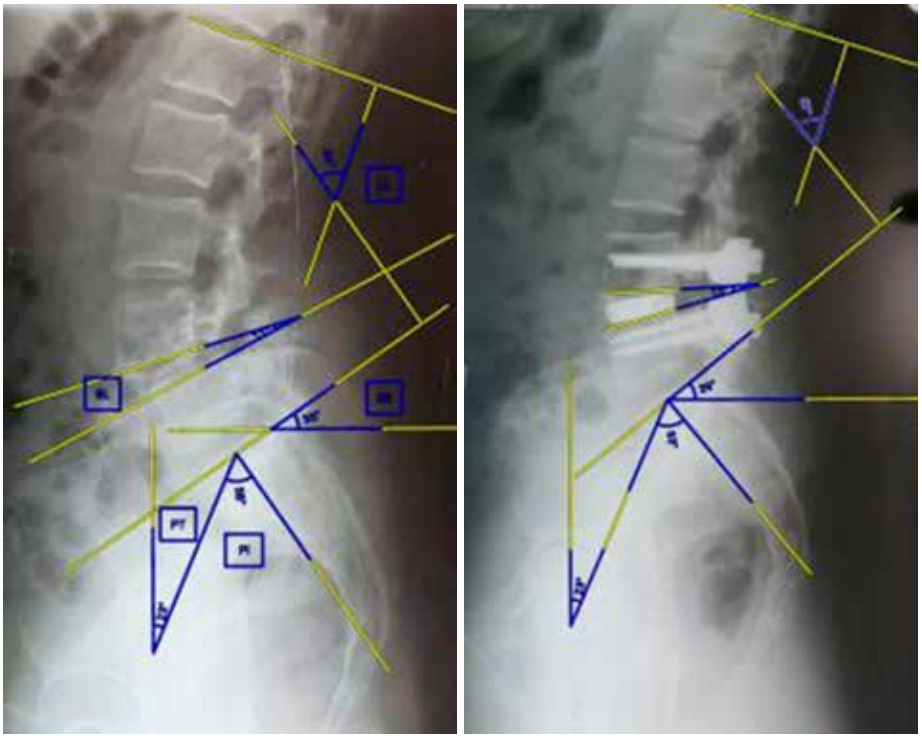

Fig. 3. Radiographic control before and after surgery using the minimally invasive posterior interbody vertebral stabilization technique with titanium distraction cages

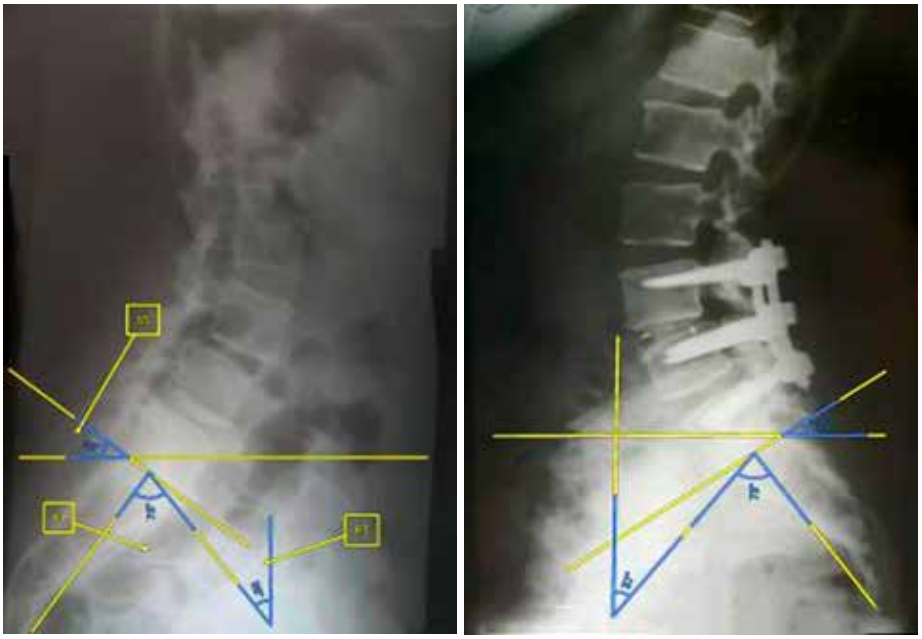

Fig. 4. Radiographic control before and after surgery using the traditional minimally invasive posterior interbody vertebral stabilization (MIPIVS) technique

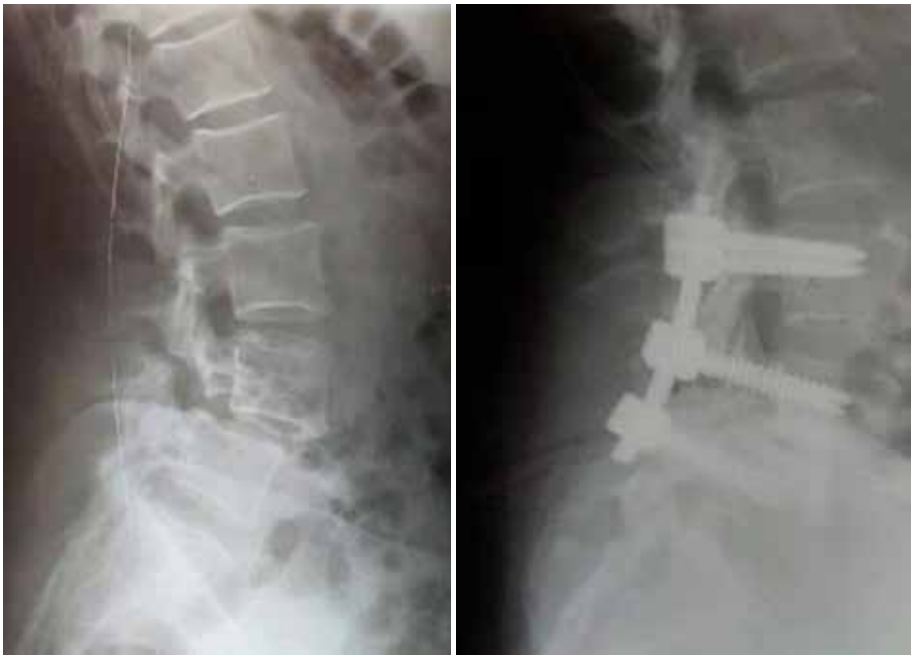

Fig. 5. Radiographic control before and after surgery using alternative methods of lumbar interbody spinal fusion

A neurological assessment was conducted to evaluate postoperative changes in neurological status, pain intensity using the Visual Analogue Scale (VAS), and functional status based on the Oswestry Disability Index (ODI).

On postoperative day 30, in the absence of contraindications, follow-up magnetic resonance imaging (MRI) was performed to assess the formation of primary bone fusion, along with a clinical and neurological examination, pain assessment via VAS, and functional status evaluation using the ODI.

Statistical Analysis

Data systematization and logical-statistical analysis were carried out using standard methods with a critical significance level of $p<0.05$. Since the data distribution deviated from normal, nonparametric statistical methods were applied. The central tendency was described using the median (Me), and variability was expressed through the determination of the lower (LQ) and upper (UQ) quartiles. The significance of pairwise intergroup differences was assessed using the Mann–Whitney U test. Frequency indicators (both absolute and relative) were compared using Fisher's exact test.

Results and discussion

Among the clinically significant parameters, the key outcome indicators were evaluated, including complaints and medical history, physical examination data (general condition, level of consciousness), duration of the surgery, surgical approach, closure of the surgical wound, intraoperative radiation exposure to medical personnel and patients, volume of intraoperative blood loss and hemotransfusion, postoperative drainage, length of hospital stay, and the incidence of complications (radiculitis, radicular dysfunction, foot flexor weakness, pain during flexion and extension of the foot, paresthesia, motor disorders, incomplete spinal fusion, pseudoarthrosis, dural tears, major vascular injuries, neural structure damage, surgical site infection, paravertebral muscle atrophy, postoperative bleeding, cerebrospinal fluid leakage, venous thromboembolism), screw loosening, malposition of surgical hardware, reoperation, body mass index, lordosis angle, lifestyle, progression of disorders, duration of conservative treatment, pain reduction after surgery, percentage of displacement before and after surgery, increase in intervertebral space, height of the foraminal opening, disability according to the ODI, and others.

The study groups were comparable in terms of age, gender ratio, anthropometric, clinical-anamnestic, and physical characteristics ($p>0.05$) ***(Table 1)***.

The surgical parameters were more favorable in the main group ***(Table 2)***.

The incidence of complications was the lowest in the study group ***(Table 3)***. No cases of postoperative hemorrhage, cerebrospinal fluid leakage, venous thromboembolism, paravertebral muscle atrophy, incomplete spondylodesis, dural injury, screw loosening, malposition of surgical hardware, neural structure damage, major vascular injury, or surgical site infection were recorded in this group. Only one reoperation was performed due to pseudoarthrosis.

Data have been obtained confirming the effectiveness of the author's method of MIPIVS using distraction cages in patients with degenerative spondylolisthesis of the lumbar spine.

The significance of this approach lies in the ongoing search within spinal surgery for optimal treatment methods that combine effective deformity correction with segmental spinal stability while reducing the incidence of postoperative complications. Minimally invasive technologies, particularly the use of transpedicular fixation and interbody cages, are currently considered among the most promising directions in the surgical management of degenerative spinal disorders [17–19].

Table 1. Clinical and anthropometric characteristics of patients with lumbar spine spondylolisthesis

Parameter	Study group (n = 4)	Comparison group (n = 10)	Control group (n = 7)	Total (n = 21)
Age, years	50 [37;53]	63 [50;66]	59 [53;60]	50 [37;53]
Men	1 (25%)	4 (40%)	1 (14%)	6 (29%)
Women	3 (75%)	6 (60%)	6 (86%)	15 (71%)
Body mass index, kg/m2	32 [28;34]	32 [28;34]	32 [28;34]	32 [28;34]
General condition	RS	RS	RS	RS
Conciousness	Clear	Clear	Clear	Clear
Achilles reflex	Weakend	Weakend	Weakend	Weakend
Tenderness	Present	Present	Present	Present
Lasègue sign	Positive	Positive	Positive	Positive
Wassermann sign	Positive	Positive	Positive	Positive
Hypoesthesia	Present	Present	Present	Present
Hyperesthesia	Present	Present	Present	Present
Meningeal signs	Absent	Absent	Absent	Absent
Plantar signs	Absent	Absent	Absent	Absent
Coordination	Preserved	Preserved	Preserved	Preserved
Paresis	Present	Present	Present	Present

Note: RS – relatively satisfactory.

Table 2. Surgical parameters for lumbar spine spondylolisthesis surgery

Parameter	Study group (n = 4)	Comparison group (n = 10)	Control group (n = 7)	Total (n = 21)
Hospital length of stay, days	13 [11;18]	9 [7;12]	11 [6;22]	10 [7;15]
Duration of surgery, minutes	180 [180;180] #	180 [160;210]	360 [240;480]	180 [180;215]
Duration of surgical approach, minutes	30 [30;30] *#	60 [60;60]	60 [60;90]	60 [30;60]
Duration of surgical wound closure, minutes	10 [8;10] *#	40 [40;40]	45 [40;50]	40 [12;40]
Duration of intraoperative radiation exposure of medical personnel, seconds	92 [87;93]	93 [90;95]	87 [81;90]	91 [87;94]
Total intraoperative radiation exposure of medical personnel, mSv:	0,22 [0,19;0,23]	0,25 [0,21;2,18]	0,20 [0,08;0,26]	0,23 [0,20;0,48]
Surgeon at the patient's side, mSv	0,08 [0,07;0,08]	0,09 [0,07;1,05]	0,07 [0,03;0,09]	0,08 [0,07;0,18]
Assisting staff at medium distance, mSv	0,06 [0,05;0,07]	0,07 [0,07;0,09]	0,06 [0,02;0,08]	0,07 [0,06;0,08]
Other personnel at a greater distance, mSv	0,03 [0,03;0,04]	0,05 [0,04;0,08]	0,04 [0,01;0,05]	0,23 [0,20;0,48]
Intraoperative patient exposure, mSv	2 [1;4]	1 [1;2]	1 [1;5]	2 [1;3]
Intraoperative blood loss, ml	100 [100;100] *#	200 [200;300]	500 [400;600]	200 [100;400]
Haemotransfusion	Not performed	1 (10%)	Not performed	1 (5%)
Haemotransfusionvolume, ml	–	600 [600;600]	–	600 [600;600]
Postoperative drainage	Not performed	3 (30%)	1 (14%)	4 (19%)
Postoperative drainage volume, ml	–	0 [0;300]	0 [0;300]	0 [0;0]

Table continued 2. Surgical parameters for lumbar spine spondylolisthesis surgery

Parameter	Study group (n = 4)	Comparison group (n = 10)	Control group (n = 7)	Total (n = 21)
Pain reduction after surgery, difference score	4 [4;4]#	3 [3;4]	2 [1;2]	3 [3;4]
Displacement, %:				
preoperatively	20 [20;25]	17,5 [10;30]	25 [20;30]	20 [15;30]
postoperatively	5 [5;5]	5 [0;15]	15 [0;25]	5 [0;15]
Sagittal vertical axis displacement, cm:				
preoperatively	10 [8;11]	10 [7;12]	10 [8;12]	10 [8;12]
postoperatively	5 [4;6]	6 [5;7]	6 [5;8]	6 [5;7]
Pelvic tilt angle, deg:				
preoperatively	50 [49;52]	50 [48;53]	58 [56;60]	54 [50;57]
postoperatively	52 [51;53]	52 [50;55]	60 [58;62]	56 [54;58]
Pelvic incidence angle, deg:				
preoperatively	19 [18;20]	24 [22;27]	30 [29;33]	25 [23;27]
postoperatively	16 [15;17]	22 [20;25]	28 [26;30]	25 [19;23]
Sacral slope angle, deg:				
preoperatively	31 [30;32]	30 [28;33]	30 [28;32]	31 [30;32]
postoperatively	34 [33;35]	32 [30;35]	33 [31;35]	33 [31;35]
Increase in intervertebral space, mm	10 [9;11] *	8 [5;9]	11 [8;12]	9 [7;10]
Increase in foraminal height, mm	2,1 [2,0;2,1]	2,2 [1,9;2,2]	1,9 [1,8;1,9]	2,1 [1,9;2,2]
Duration of conservative treatment, months	12 [12;12]	12 [3;18]	12 [12;18]	12 [6;18]
Duration of rehabilitation, months	6 [6;6]	6 [6;12]	12 [6;18]	6 [6;12]
Dynamics of ODI disability, score	10 [10;15]	15 [10;25]	18 [10;20]	15 [10;20]

Note: * – statistically significant difference from the comparison group ($p<0.05$); # – the difference from the control group is statistically significant ($p<0.05$).

Table 3. Incidence of complications following surgical intervention for lumbar spine spondylolisthesis

Parameter	Study group (n = 4)	Comparison group (n = 10)	Control group (n = 7)	Total (n = 21)
Postoperative hemorrhage	–	3 (30%)	1 (14%)	4 (21%)
Postoperative cerebrospinal fluid (CSF) leakage	–	1 (10%)	–	1 (5%)
Venous thromboembolism	–	–	–	–
Atrophy of the paravertebral muscles	–	10 (100%)	1 (14%)	11 (52%)
Radiculitis with dysfunction of spinal nerve roots, manifested as:	1 (25%)	3 (30%)	1 (14%)	5 (24%)
Autonomic disturbances:				
Frequency	4 (100%)	10 (100%)	2 (29%)	16 (76%)
Duration (weeks)	1	1	1	1
Hypoesthesia:				
Frequency	1 (25%)	4 (40%)	1 (14%)	6 (29%)
Duration (weeks)	1	1	1	1

Table continued 3. Incidence of complications following surgical intervention for lumbar spine spondylolisthesis

Parameter	Study group (n = 4)	Comparison group (n = 10)	Control group (n = 7)	Total (n = 21)
Pain during foot flexion and extension:				
Frequency	1 (25%)	3 (30%)	1 (14%)	5 (24%)
Duration (weeks)	1	1	1	1
Paresthesia:				
Frequency	4 (100%)	3 (30%)	1 (14%)	8 (38%)
Duration (weeks)	1	2	2	2
Weakness of foot flexors:				
Frequency	–	2 (20%)	1 (14%)	3 (14%)
Duration (weeks)	–	4	4	4
Screw loosening	–	1 (10%)	1 (14%)	2 (10%)
Malposition of surgical hardware	–	1 (10%)	1 (14%)	2 (10%)
Incomplete spinal fusion (insufficient spondylodesis)	–	1 (10%)	1 (14%)	2 (10%)
Dural sac injury	–	2 (20%)	–	2 (10%)
Damage to neural structures	–	2 (20%)	–	2 (10%)
Injury to major blood vessels	–	–	–	–
Surgical site infection	–	1 (10%)	1 (14%)	2 (10%)
Reoperation	1 (25%)	1 (10%)	–	2 (10%)

The results of our study demonstrated that patients in the study group, who underwent surgery using the author's technique, showed more pronounced positive dynamics in functional recovery compared to the standard treatment and control groups. Pre- and postoperative assessments revealed a significant reduction in pain intensity on the VAS. In the study group, pain levels decreased by an average of 4 points, while in the comparison group the reduction was 3 points, and in the control group — 2 points (the differences were statistically significant). Furthermore, assessment of functional status using the Oswestry Disability Index (ODI) showed marked improvement in the main group (a reduction of 10 points), indicating more effective restoration of the spinal motion segment and minimal limitations in daily activities.

A critically important outcome is the restoration of intervertebral disc height following surgery, as this parameter is key to ensuring the stability and functionality of the spinal motion segment. In the study group, postoperative increase in intervertebral disc height averaged 10 [9;11] mm, which was higher than that observed in the comparison group (8 [5;9] mm, $p<0.05$). Restoration of disc height plays a decisive role in reducing nerve structure compression, thereby alleviating neurological deficits and pain symptoms. Another essential aspect is the preservation of spinopelvic balance, a major factor in achieving a sustained positive clinical outcome. According to the collected data, the correction of sacral and pelvic tilt angles was most optimal in the main group, further supporting the effectiveness of the applied technique in ensuring biomechanical stability.

The assessment of intraoperative parameters demonstrated that the use of distraction cages significantly reduced the duration of the surgical procedure and hospitalization, as well as the volume of blood loss. The average operative time in the study group was 180 [180;180] minutes, which aligns with the standard parameters for MIS-PLIF (minimally invasive surgery posterior lumbar interbody fusion) and was significantly shorter ($p<0.05$) compared to the control group, where the operative time was 360 [240;480] minutes. The reduction in operative time directly contributes to a decreased risk of intraoperative complications such as blood loss and infectious complications. Intraoperative blood loss in the study group was considerably lower—100 [100;100] ml—compared to the comparison group, which recorded 200 [200;300] ml ($p<0.05$), and the control group, where blood loss amounted to 500 [400;600] ml ($p<0.05$). This reduction minimizes the need for blood transfusions and lowers the risk of hypovolemic shock.

An analysis of postoperative complications revealed the lowest incidence in patients treated using the authors' proprietary technique. Specifically, no cases of paravertebral muscle atrophy were observed in the study group, while the incidence in the comparison group was 100% and 50% in the control group ($p<0.05$). This outcome is attributed to the fundamentally

different surgical access technique, indicating that the minimally invasive approach significantly reduces the risk of iatrogenic damage to the musculo-ligamentous apparatus and promotes improved postoperative recovery.

The rate of postoperative bleeding was 27% and 33% in the comparison and control groups, respectively, whereas no such cases were observed in the main group ($p<0.05$). A significant reduction in the risk of radiculitis with spinal nerve root dysfunction was also of clinical importance. This complication occurred in only 25% of cases in the main group, compared to 30% in the comparison group and 50% in the control group ($p<0.05$).

These findings are consistent with contemporary studies demonstrating the advantages of minimally invasive techniques in the treatment of degenerative spondylolisthesis. Such methods reduce the risk of surgical complications, improve postoperative outcomes, and shorten the rehabilitation period. In particular, significant improvement in sagittal balance parameters has been observed in patients who underwent treatment with distraction cages within the MIS-PLIF framework [20, 21].

Conclusions

1. The dimensions of the vertebral canal were studied, and the dynamics of neurological impairments were assessed following surgical treatment of patients with degenerative lumbar spondylolisthesis using a traditional approach.

2. The magnitude of segmental lordosis, spine-pelvic balance parameters, and sagittal spinal contour were determined as indicators of spinal functional status before and after traditional surgical treatment in patients with degenerative lumbar spondylolisthesis.

3. A proprietary method of MIPIVS using distraction cages was substantiated and developed.

4. Criteria for evaluating the effectiveness of the proposed MIPIVS method with distraction cages were identified.

5. Using a biomechanical model, the potential for restoring segmental lordosis, spine-pelvic balance parameters, and sagittal spinal contour—as indicators of spinal functional condition—was assessed. Additionally, the stress-strain state of the system "transpedicular construct – spinal motion segment – distraction cage" was analyzed.

Prospects for further research

Clinical validation of minimally invasive posterior interbody stabilization using distraction cages in patients with lumbar spondylolisthesis is planned.

Disclosure

Conflict of Interest

The authors declare no conflict of interest.

Ethical Standards

All procedures performed on patients in the course of this study complied with the ethical standards of the institutional and national research ethics committees and with the 1964 Helsinki Declaration and its subsequent amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Funding

The research received no external funding.

Acknowledgements

The authors express their gratitude to the administration of the Municipal Non-Profit Enterprise of the Kharkiv Regional Council "Regional Clinical Hospital", Kharkiv National Medical University, and the Prof. M. I. Sitenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine for the opportunity to conduct this research based on their facilities; to LLC "Kalmykov Consulting" for assistance in systematizing the results of the clinical research phase; and to all colleagues for their constructive discussion, validation, and implementation of the findings.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):65-68
doi: 10.25305/unj.324776

Percutaneous laser microdiscectomy in the treatment of multilevel protrusions and herniations of lumbar intervertebral discs

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Received: 14 March 2025
Accepted: 07 April 2025

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Objective: To develop a clear treatment strategy for multilevel protrusions and herniations of the lumbar spine using the method of percutaneous laser microdiscectomy (PLMD).

Materials and Methods: The study involved 620 patients diagnosed with multilevel lumbar intervertebral disc (IVD) protrusions and herniations, all of whom underwent PLMD. The patients ranged in age from 20 to 50 years, including 360 men and 260 women. All patients underwent preoperative magnetic resonance imaging, and 62% additionally underwent computed tomography. The patients were categorized into four groups: group I (n = 78): PLMD was performed at a single level with herniations characterized by posterior-central or paramedian localization and a sagittal size not exceeding 7 mm; group II (n = 24): PLMD was performed on discs with herniations similar to those in group I, but accompanied by protrusions at other levels (sagittal size 4–6 mm); group III (n = 380): PLMD was performed in a single session on two levels with protrusions (sagittal size 4–6 mm); group IV (n = 138): PLMD was performed in a single session on three levels with protrusions (sagittal size 4–6 mm). All procedures were performed under fluoroscopic guidance using a C-arm system (Phillips, Netherlands). Pain intensity was evaluated using the Visual Analog Scale (VAS) preoperatively and during the two-week postoperative period. Treatment outcomes after one month were assessed using the McNab scale. Long-term quality of life was evaluated using the Oswestry Disability Index.

Results: In Group I, the initial radicular pain (measured by VAS) was more severe but significantly decreased after one week postoperatively, while lumbar pain (lumbalgia) remained moderate over the two-week follow-up. In Group II, the reduction in radicular symptoms mirrored that of Group I, with the greatest treatment effect ($d = 0.7$, $p < 0.05$); however, lumbalgia only decreased after two weeks ($p > 0.05$). In Groups III and IV, radicular pain decreased similarly to Group II. However, in Group IV, the intensity of lumbalgia remained high and exceeded the baseline even after two weeks ($p > 0.05$). At the one-month follow-up, the highest rate of excellent outcomes was observed in Group I and the lowest in Group IV, though differences between the groups were not statistically significant ($p > 0.05$). These findings suggest that post-PLMD pain severity is largely influenced by lumbalgia rather than radicular pain.

Conclusions: Percutaneous laser microdiscectomy is an effective method for treating protrusions and non-sequestered small herniations of the lumbar spine. The method is most appropriate and efficient when performed in a single session for two symptomatic lumbar IVD protrusions. Although it is technically feasible to treat three symptomatic protrusions in a single session, such an approach is considered less advisable.

Keywords: *multilevel protrusions; multilevel herniations; percutaneous laser microdiscectomy*

Introduction

Protrusions and herniations of the lumbar intervertebral discs (IVDs) are among the leading causes of back pain. According to computed tomography (CT) and magnetic resonance imaging (MRI) data, disc protrusions and herniations at two or more levels are detected in approximately 50% of patients presenting with back pain [1, 2]. Although the majority of IVD protrusions are asymptomatic, there are cases in which such protrusions cause not only localized lower back pain (lumbalgia) but also radicular pain syndromes. In contrast, lumbar disc herniations are more commonly associated with radicular pain and to a lesser extent with lumbalgia. It is well established that most protrusions respond successfully to conservative treatment methods [3]. This is also true for small-sized herniations (<6 mm) without signs of sequestration. A minority of patients, however, do not benefit from conservative therapy, yet they do not meet the absolute indications for open surgical intervention. It has been found that these patients may benefit from percutaneous techniques, among which laser methods are the most widely used [4, 5]. Introduced in the 1980s, this technique has gained international traction and is now employed in many neurosurgical and orthopedic clinics [6–9]. The method has been described under various names, including nucleoplasty, intradiscal

decompression, and vaporization [10, 11]. Based on the proposal by Ye.H. Pedachenko, this approach was termed "percutaneous laser microdiscectomy" (PLMD) [12]. Experimental and clinical studies have demonstrated that through the effects of ablation and vaporization, the laser beam can reduce the volume of the IVD by 15–25% [13].

Currently, there is no clear consensus regarding the management strategy for multilevel lumbar disc protrusions and herniations [14]. It remains uncertain whether multiple affected discs should be treated in a single session. If so, how many discs can be safely operated on during one procedure? Furthermore, if multiple disc interventions are permitted, what is the acceptable level of radiation exposure? These questions require definitive answers.

Objective: To develop a clear treatment strategy for multilevel protrusions and herniations of the lumbar spine using the method of percutaneous laser microdiscectomy (PLMD).

Materials and methods

The study was conducted at the "Endoscopic Neurosurgery" Medical Center (Dnipro), where PLMD procedures have been performed since 1997.

Study participants

A total of 620 patients aged between 20 and 50 years participated in the study. Among them, 360 were men and 260 were women.

All patients provided written informed consent to participate in the study.

The study protocol was approved by the ethics and bioethics committee of Dnipro State Medical University (Minutes No. 25 dated 19 February 2025).

Group characteristics

The patients were divided into four groups. Group I included 78 patients who underwent PLMD on a single IVD with posterior median or paramedian herniation, with a sagittal size not exceeding 7 mm. Group II consisted of 24 patients who underwent PLMD on a single IVD, where herniations were similar to those in group I and were accompanied by protrusions at other spinal levels (sagittal size of 4–6 mm). Group III included 380 patients who underwent PLMD in a single session on two IVDs with protrusions (sagittal size of 4–6 mm). Group IV comprised 138 patients who received PLMD in a single session on three IVDs with protrusions (sagittal size of 4–6 mm).

Inclusion criteria

Patients were selected based on criteria commonly cited in the literature [15]: age not exceeding 50 years, preservation of disc hydration and sufficient disc height (at least 2/3 of normal height), herniation size not exceeding 6 mm, absence of ossifying ligamentosis, degenerative spinal canal stenosis, and spondylolisthesis. Protrusions of at least 3 mm were considered.

Study design

Only patients treated within the last 10 years using diode lasers Surgilas (Germany) and Lika-Surgeon (Cherkasy, Ukraine) were included. The laser wavelength was 980 nm, with an energy load not exceeding 800 J per disc. The duration of each pulse was 1 second with an energy output of 15 J. All patients underwent preoperative magnetic resonance imaging (MRI) using various 1.5 Tesla machines. Additionally, 62% of the patients also had computed tomography (CT) scans performed using a 16-slice Toshiba scanner (Japan).

Surgeries were performed under fluoroscopic guidance using a C-arm system ("Philips", Netherlands).

Pain intensity was assessed preoperatively and within 2 weeks postoperatively using the Visual Analogue Scale (VAS). Surgical efficacy was evaluated at 1 month postoperatively using the McNab classification. In the long-term follow-up, quality of life was assessed using the Oswestry Disability Index.

Statistical analysis

The analysis of the obtained data was conducted using methods of descriptive and analytical biostatistics. Quantitative indicators are presented as arithmetic mean and its standard error (M±m). The therapeutic effect size was calculated using Cohen's d method, and its statistical significance was determined using the paired Student's t-test. A p-value of <0.05 (<5%) was considered statistically significant for all types of analysis performed [16].

Results

The neurological status of the patients was heterogeneous. In the patients of groups I and II, radicular syndrome predominated more frequently (76.4%), while in groups III and IV, lumbalgia was more common. In groups I and II, the average severity of radicular pain syndrome was (7.3±1.6) and (7.50±1.46) points respectively, and the pain syndrome associated with lumbalgia was (6.40±0.78) and (5.30±0.91) points. In patients of groups III and IV, the respective values were (6.70±0.85) and (6.20±1.47) points, and (6.10±1.34) and (6.30±1.54) points.

In group I, laser loading was applied to the intervertebral discs from L2 to L5 with approximately 880 J, and to the L5-S1 herniated IVDs with approximately 700 J, due to the smaller volume of this disc compared to others. In this group, PLMD was limited to the herniated disc only (76.4%). In contrast, group II included PLMD of the herniated disc and, in 25.6% of cases, the additional disc with a protrusion. This was due to the presence of a predominantly radicular pain when both a hernia and one protrusion were present, prompting intervention on the herniated disc only. In patients presenting with both radicular pain and pronounced lumbalgia, PLMD was performed on both affected discs. In group III, which involved multilevel disc protrusions, the disc corresponding to the radicular pain was operated on first, followed by the disc with the more pronounced protrusion (4–6 mm). In group IV, determining the cause of lumbalgia was more complex due to the presence of three or more IVDs protrusions. In 16% of patients, the pain could be localized to a lumbar region either above or below the most affected segment. In such cases, PLMD was performed on the L1-L2, L2-L3, and L3-L4 discs or on the L3-L4, L4-L5, and L5-S1 discs. In other instances, it was not possible to determine which of the affected discs was primarily responsible for the lumbalgia. Consequently, PLMD was performed in a single session on the three IVDs with the largest protrusions.

This article contains some figures that are displayed in color online but in black and white in the print edition.

In group I, the initial intensity of radicular pain according to the VAS was significantly higher, but it decreased within the first week and remained at a low level over the following two weeks. Meanwhile, the severity of lumbalgia remained at a moderate level during the same period ***(Table 1)***.

In group II, in which PLMD was performed for IVD with both herniation and protrusion, the dynamics of radicular pain were similar to those observed in group I. The treatment effect on radicular pain was the most pronounced in this group ($d = 0.7$, $p < 0.05$). At the same time, the intensity of lumbalgia during the first week even increased and only began to slightly decrease after two weeks; however, this effect was not statistically significant ($p > 0.05$).

The dynamics of pain syndrome in patients of groups III and IV did not differ significantly from group II regarding radicular pain: a gradual decrease in pain intensity was observed within the first week and continued in the second week. However, in patients of group IV, who underwent PLMD in a single session for three IVDs with protrusions, the intensity of lumbalgia was significantly higher than in the other groups. After two weeks, this value remained higher than at baseline ($p > 0.05$), indicating a more severe post-procedural response in these patients.

One month after PLMD, the patients' condition was assessed using the McNab scale ***(Fig. 1)***. The highest frequency of excellent outcomes was recorded in Group I, while the lowest was observed in Group IV; however, the differences between the groups were not statistically significant ($p>0.05$). It can be assumed that the intensity of pain following PLMD is largely associated with lumbalgia rather than radicular pain. At the same time, a tendency was observed: as the number of IVDs treated with PLMD during a single session increased, patients experienced greater difficulty tolerating lumbalgia.

Long-term outcomes were evaluated using the Oswestry Disability Index before surgery and at various intervals thereafter. A total of 312 patients were successfully followed up and provided responses. The average follow-up duration was (2.40 ± 0.38) years.

The outcomes obtained using the Oswestry Disability Index ***(Table 2)*** indicated that in all groups, a statistically significant improvement was observed in the long-term follow-up period ($p<0.001$ for each group separately). The largest effect sizes were recorded in group II ($d = -2.02$, $p<0.001$) and group I ($d = -1.18$, $p<0.001$). These findings suggest that PLMD is an effective treatment for lumbar disc protrusions and small herniations of the lumbar spine. Procedures performed on two levels in a single session

Table 1. Pain intensity on the VAS following percutaneous laser microdiscectomy

Pain type	Group	Number of patients	VAS pain intensity, points			Cohen's d*
			Baseline	After 1 week	After 2 weeks	
Radicular	I	78	7,30±1,62	3,60±1,44	2,70±0,83	-0,40**
	II	24	7,50±1,46	3,5±1,27	2,20±1,62	-0,70**
	III	380	6,70±0,85	2,90±1,34	1,90±0,78	-0,46**
	IV	138	6,20±1,47	2,60±1,15	1,80±1,52	-0,45**
Lumbalgia	I	78	6,40±0,78	4,50±1,36	3,80±1,65	-0.22
	II	24	5,30±0,91	5,90±1,83	4,10±1,75	-0,17
	III	380	6,10±1,34	6,20±1,46	4,10±0,97	-0,11
	IV	138	6,30±1,54	7,90±1,73	7,20±1,47	0,06

Notes:
** represents the effect size comparing baseline pain intensity with values after 2 weeks.*
***statistically significant treatment effect ($p < 0.05$) according to Student's paired t-test.*

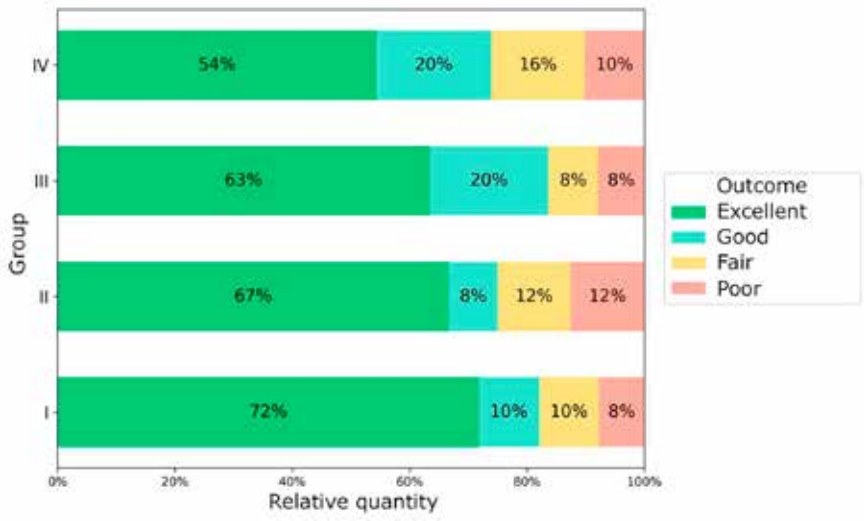

Fig. 1. Assessment of patients' condition after percutaneous laser microdiscectomy using the McNab scale

Table 2. Evaluation of quality of life in the long-term period after percutaneous laser microdiscectomy using the Oswestry Disability Questionnaire

Group	Number of patient responses	Before surgery, %	In the long-term period, %	Cohen's d	p
I	46	78,3±6,72	21,5±7,45	-1,18	<0,001
II	20	79,8±7,22	20,3±5,87	-2,02	<0,001
III	167	75,8±6,89	18,6±6,64	-0,65	<0,001
IV	79	73,7±5,97	27,7±7,87	-0,74	<0,001

resulted in a slight deterioration in patients' conditions during the first two weeks postoperatively, particularly in group IV. However, one month after surgery, a significant clinical improvement was observed across all patient groups. According to the McNab criteria, patients who underwent PLMD on three levels in one session showed poorer early outcomes. Nevertheless, in the long-term follow-up, the results across all groups were comparable. This supports the conclusion that performing PLMD on two lumbar IVDs in one session is sufficiently effective. Patients in this category experienced mild deterioration in the early postoperative period, which was generally well tolerated, and by one month post-surgery, their condition was similar to that of group I, where PLMD was performed on a single IVD. In contrast, patients in group IV experienced an intensified pain syndrome of the lumbalgia type in the early postoperative period, which significantly worsened their overall condition. Although their condition improved one month after surgery, it did not reach the levels observed in the other groups. In the long-term follow-up, the quality of life of patients in group IV, as measured by the Oswestry Disability Index, remained worse than in the other groups. This suggests that performing PLMD on three IVDs in a single session increases radiation load on the lumbar spine, which negatively affects patient outcomes. Therefore, in our opinion, while technically feasible, PLMD on three IVDs in one session is not advisable.

Conclusions

1. Percutaneous laser microdiscectomy is an effective method for the treatment of lumbar disc protrusions and small non-sequestered herniations.

2. Performing PLMD in a single session on two symptomatic lumbar intervertebral disc protrusions is effective and reasonable.

3. Although technically possible, performing PLMD on three symptomatic lumbar intervertebral disc protrusions in a single session is not advisable.

Disclosure

Conflict of interest

The authors declare no conflict of interest.

Ethical standards

All procedures involving patients during the study complied with the ethical standards of institutional and national ethics committees and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Funding

The study received no external funding or sponsorship.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):69-74
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Unlocking Relief: Lower Half Laminectomy for Lumbar Disc Herniation under Spinal Anesthesia: An Institutional Perspective

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Received: 20 March 2025
Accepted: 25 April 2025

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Lumbar disc herniation is a prevalent spinal condition characterized by the displacement of intervertebral disc material leading to back pain and neuropathies. Surgical intervention, including decompressive laminectomy, is often recommended for patients who fail to respond to conservative treatment. The procedure of unilateral or bilateral lower half laminectomy, with or without disc herniation removal, has been described as an effective surgical technique for treating lumbar disc herniations.

Purpose: The aim of the study was the assessment of outcomes including complications in patients undergoing limited laminectomy with discectomy.

Material and methods: A total of 188 patients over a period from May 2022 till May 2024 were prospectively studied.Outcomes were assessed using Odom's criteria, including complication, recovery status at subsequent follow up at 1 and 3 months.

Results: Out of 188 patients, single disc herniations were seen in 155 while 2-level disc were seen in 33 cases. Among these, L5-S1 level herniation was most common , and in multi-disc herniation, L5-L5,L5-S1 levels were common. Most patients presented with radicular pain(127) followed by motor deficits or sensory deficits. Post operative recovery status was classified as excellent in the majority of cases (121 out of 188) with very less in fair and none in poor category. The recovery was gradually towards better grades in subsequent follow-ups. Duration of surgery was less than 1 hour in about 90% cases (16 out of 188).

Conclusions: All cases were done under spinal anaesthesia. Adequate surgical exposure was obtained. The technique allowed for early mobilization, reduced hospital stay apart from a shorter learning curve requirement as compared to microscopic or endoscopic procedures. During discectomy the thickened ligamentum flavum (causing canal stenosis/narrowing) can also be dealt in single procedure. This procedure could be a safer alternative to the newer modalities of minimally invasive surgeries for lumbar decompression.

Keywords: *limited laminectomy; open decompression; disc herniation*

Introduction

Lumbar disc herniation is a prevalent spinal condition characterized by the displacement of intervertebral disc material, frequently resulting in significant back and leg discomfort, and in severe instances, neurological impairments such as weakness, numb sensations, and bladder/bowel dysfunction [1]. Surgical intervention, including decompressive laminectomy, is often recommended for patients who fail to respond to conservative treatments or those with severe or progressive neurological deficits [2]. While open surgical procedures have traditionally been the standard approach, in recent years, minimally invasive surgical techniques have gained popularity due to their potential benefits, such as reduced surgical trauma, shorter hospital stays, and faster recovery times [3].

One such minimally invasive technique is the lower half laminectomy, which involves the removal of the inferior portion of the lamina to access and decompress the affected spinal level [4]. At our institute, single-level or double -level discectomies without fixation are usually administered under spinal anaesthesia unless the patient specifically refuses or there is any high risk/ comorbidities associated,thereby prohibiting the use. In this case series, all procedures which were done under spinal anesthesia have been retrospectively studied from May 2022 till May 2024.

The procedure of unilateral or bilateral lower half laminectomy, with or without disc herniation removal, has been described as an effective surgical technique for treating lumbar disc herniations. Performing these lower half laminectomies under spinal anesthesia, rather than general anesthesia, confers several advantages while post operative complication rates are comparable to that associated with microdisscectomies or endoscopic procedures etc. and also avoiding complications related to general anaesthesia.

Purpose: The aim of the study was the assessment of outcomes including complications in patients undergoing limited laminectomy with discectomies.

Materials and methods

Type of study:

Prospective cohort study

Study duration:

May 2022- May 2024

Study location:

Department of Neurosurgery, NRSMCH, Kolkata.

Study population:

All subsequently admitted patients undergoing single or double level limited laminectomy and discestomies/ decompression without fixation under spinal anaesthesia.

Exclusion criteria:

Patients with severe canal stenosis accompanied by facet arthropathy, any radiologic evidence of subluxation, or multilevel involvement (more than three levels) were excluded from the study(as they required more extensive decompression with or without fusion/ fixation). Prior to any surgical intervention, patients underwent clinical assessment, MRI, and dynamic X-rays of the lumbosacral spine. Postoperative evaluations were carried out according to Odom's criteria (Culloch, 1996) [5].

Sample size:

A total of 188 patients were studied.

All cases were conducted in the prone position under spinal anesthesia using a Bupivacaine/Fentanyl mixture.

Details of the Operative Procedure:

Following spinal anesthesia, patients were positioned prone. A midline incision was made one level above and below the involved segment. C-arm intensifier was utilized, especially when sacralization or lumbarization was identified in preoperative imaging. The spine and laminae were exposed, centering on the affected disc space. Portions of the spinous process and interspinous ligament were excised. The lower halves of both laminae were removed until the epidural fat became visible through the ligamentum flavum in the midline. ***(Fig. 1)***. The ligamentum flavum was excised bilaterally, and in certain cases, the overhanging portions of the hypertrophied medial facets were removed using a Kerrison punch. A standard technique was employed for discectomy, ensuring the complete removal of all visible disc material. Both nerve roots were examined for any additional compressive elements before they entered their respective foramina. For L5-S1 disc prolapse, only ligamentum flavectomy was performed with limited laminectomy (even less than the lower half) to facilitate adequate discectomy. The wounds were closed in layers after achieving proper hemostasis. For illustration images from a case of L5-S1 disc prolapsed are presented(pre-operative MRI and post operative X-ray) ***(Fig. 2-4)***.

The patients were encouraged to ambulate as soon as they could. An external orthosis (lumbar-sacral brace) was recommended for all the patients and gradually withdrawn depending on the resolutions of symptoms. The brace was typically worn longer in patients who underwent double level decompression compared to those treated at a single level.

Follow up:

Postoperative clinical assessment has been done in the next day and at discharge according to Odom's Criteria.

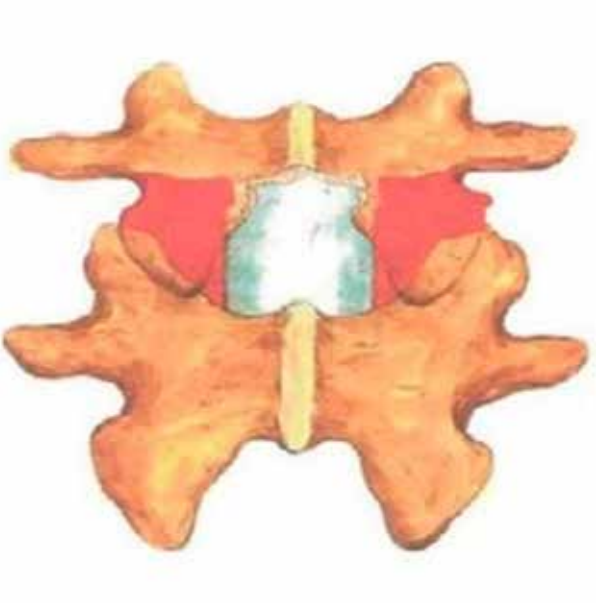

Fig. 1. Diagrammatic representation of the lower half laminectomy of lumbar vertebra: the shaded portion in red is the part to be removed to gain access to the prolapsed disc part, white shiny part in mid represents the dural covering of spinal cord

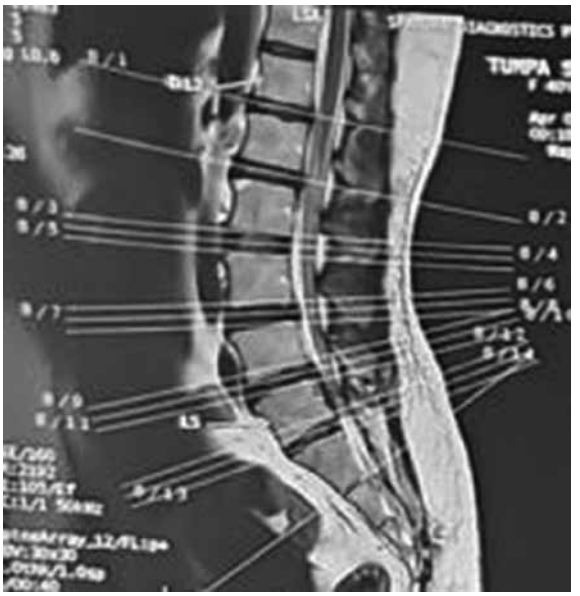

Fig. 2. Sagittal T2-weighted MRI showing L5-S1 disc prolapse

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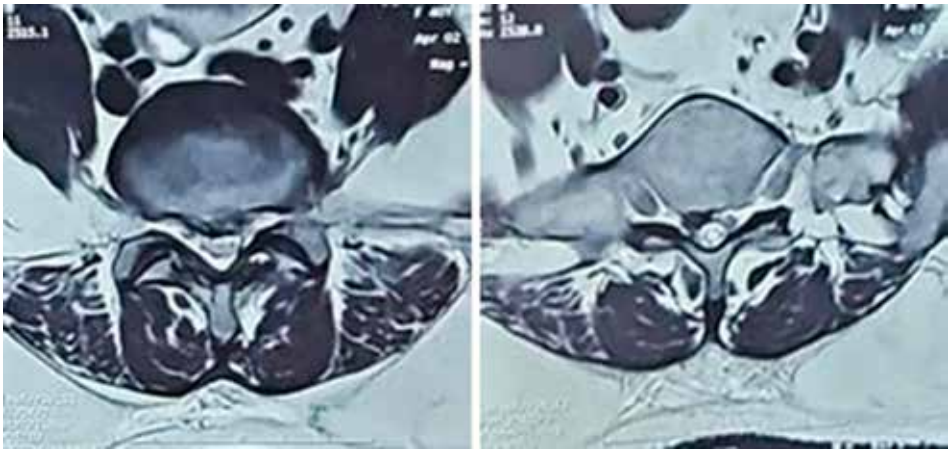

Fig. 3. Axial T2-weighted MRI showing the central disc prolapse with right-sided protusion compressing the nerve roots

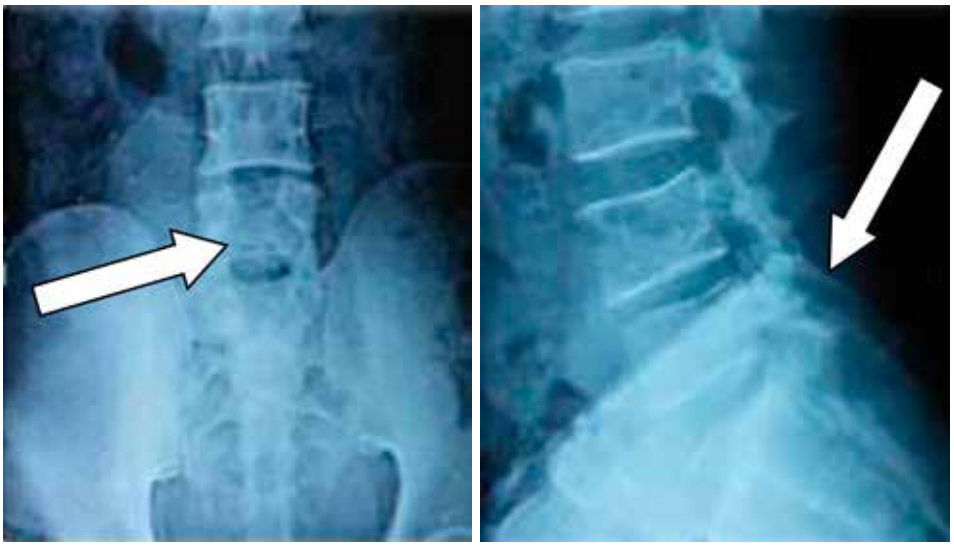

Fig. 4. X-ray of the LS spine (anteroposterior (A) and lateral (B) views) done postoperatively demonstrating the post laminectomy defects(indicated by arrows)

Odom's Criteria:

• Excellent: All preoperative symptoms relieved; abnormal findings improved.

• Good: Minimal persistence of preoperative symptoms; abnormal findings improved or unchanged.

• Fair: Definite relief of some preoperative symptoms; other symptoms slightly improved orunchanged.

• Poor: Preoperative symptoms and signs are unchanged or, exacerbated.

Results

The general characteristics and the distribution of symptoms among the population were grouped as in ***Table 1***.

The majority of patients were male (63.3%) with the most prevalent age group being 41-60 years (55.3%) followed by 21-40 years group (28.2%) representing the major working force of the region. Patients presented with either isolated or multiple symptoms arising out of disc proplapse varying from mono-radiculopathy or localized pain to neurological deficits(motor, sensory, autonomic). Radiculopathy was the most common symptom, observed in more than 2/3rdof the patients with a few having autonomic involvements also (7%).

Most of the surgeries (86.7%) were completed within an hour, while the rest (13.3%) were performed within the next hour. Multilevel involvement, calcified or sclerosed discs were among few reasons leading to prolonged surgical durations. Typically, the patients are discharged on the 3rd postoperative day. However, the poor patients residing in remote areas with no proper access to healthcare facilities are kept for 5-6 days, and discharged after wound inspection, unless there are complications. Postoperative complications were observed in 33 cases (17.5%) and ranged from minor surgical site infections (SSI), such as serous discharge or erythema to CSF leaks. Only 2 patients required readmissions for SSI management due tocomorbid condition (Diabetes mellitus type 2) and both were successfullydischarged the following week.The remaining cases were conservatively managed with antibiotics and other supportive measures. A subset of patients

(n=25) have prolonged hospital stay of more than 7 days ***(Table 2)***.

Postoperative recovery was assessed using Odom's criteria. Majority of the patients (64% or 2/3rd) demonstrated excellent recovery at the time of discharge and this proportion gradullay improved towards each follow-up reaching 79% at 3 months. About 1/4th of patients (26%) had a good recovery while 9.6% exhibited fair recovery at the time of discharge.This number gradually progressed towards better recovery over the time with only 5% remaining in the fair category and 15% in the good category withremainder in excellent category. None of our patients had deterioration of symptoms ***(Table 3)***.

Table 1. Characteristics of the study population and distribution of symptoms

Characteristics	Number of patients		
	abs.	%	Total
Gender distribution			
Male	119	63.3	188
Female	69	36.6	
Age group			
0-20yrs	9	4.8	188
21-40 yrs	53	28.2	
41-60 yrs	104	55.3	
>60 yrs	23	12.2	
Symptoms			
Localized pain	37	19.7	188
Radicular pain	127	67.5	
Sensory deficit	93	49.5	
Motor deficit	105	55.8	
Sphincter involvement	13	7	
Levels of involvement			
L5-S1	81	43.1	155
L4-L5	57	30.3	
L3-L4	17	9	
L4-L5, L5-S1	21	11.2	33
L3-L4, L4-L5	12	6.4	

Table 2. Distribution of various surgery-related aspects

	Number of patients	
	abs.	%
Duration of surgery		
<1 hour	163	86.7
1-2 hours	25	13.3
Complications		
Surgical site infection	11	5.8
readmission	2	1.1
Dural tear	9	4.7
CSF leak	1	0.05
New onset radiculopathy	4	2.2
Discitis	2	1.1
General complications	7	3.7
Total	33	17.5
Hospital Stay		
<7days	163	86.7
>7days	25	13.2

Table 3. Recovery status of patients at various intervals in post-operative period

Post-op recovery status	At the time of discharge		At first follow-up (1 month)		At 3rd month follow up	
	abs.	%	abs.	%	abs.	%
Excellent	121	64.3	143	76	149	79.2
Good	49	26	33	17.5	29	15.4
Fair	18	9.6	12	6.3	10	5.3
Poor	-	-	-	-	-	-
Total	188					

Discussion

Lumbar disc pathologies are a major cause of morbidity among the Indian population, where the primary occupation of majority is agriculture and related activities. Addressing this issue, often surgical decompression is required depending on the gravity of the pathology and deficits or symptoms associated which are often not amenable to medical management. While discectomy was first initiated in 1908, since then many advancements have taken place and newer modalities like chemonucleolysis, endoscopic discectomy, microscopic discectomy, percutaneus laser-assisted decompression have come into existence. Each modality presents its own set of advantages and limitations. However,still in most parts of world andin resource-poor countries like ours, open decompression with discectomy is mostly practiced.

Various comparative studies have been done comparing the efficacy and outcomes of open discectomy with other modalities. A recent study of Pravesh et al. in 2022 comparing full endoscopic vs. open discectomy emphasized endoscopic method to bear more favorable results but differences were not clinically significant [6]. Another meta-analysis, comparing endoscopic and open procedures published in 2021 concluded there were no difference in leg pain reduction or functional recovery in either groups in long term follow-up [7]. Calikoglu et al. (2018) in their study of 519 patients concluded that no significant differences in outcomes, complications and re-operations due to recurrences in either groups however significantly lesser time and hospital stays were seen in microdiscectomy groups [8]. Complication rates in post-operative periods were noted in 17.5% cases, which is comparable to previous studies by Tao et al. (16.6%) in 2018 and Xu et al. (20%) in 2020 [11, 12].

Another important outcome from this study was lesser number of anaesthetic drug usage, which also had implications for perioperative infection control.Studies pertaining to microbial contamination by injecting medications into stopcocks or I.V. ports have been done and they point out to the fact that lesser the number of drugs injected,lesser times will be the handling of IV ports and lesser will be the risk of peri-operative contaminations [9]. Other major concern with SA is hypotension. It is due to sympathetic blockade resulting to decreased venous return and preload and exacerbated by prone positioning. Vasopressors may be required . Few cases had vasopressor use intraoperatively in our study which is consistent withprevious studies. Other complications of direct nerve injury attributable to SA have been reported in previous studies, however no such complications were observed in our cohort.

Our findings are comparable to those reported in the above discussed literature [6, 10, 11, 12]. Both microdiscectomy and endoscopic discectomy present notable limitations, such as the necessity for expensive instruments, the requirement for specialized centers, and the need for advanced expertise. Moreover, these techniques are particularly ineffective in managing large central discs and ligamentum hypertrophy, as well as spinal canal pathologies beyond disc-related issues, which can lead to a heightened recurrence rate compared to open surgical approaches (Arvind et al., 2014) [10]. Although microdiscectomy and endoscopic discectomy are characterized by minimal exposure, the limited laminectomy method employed in our study provided sufficient access to the affected segment while significantly reducing the likelihood of residual disc material and delayed instability. Moreover, this technique can be executed without the need for specialized instruments, making it relatively straightforward to learn and master.

Conclusion

In a limited resource setting like ours and most parts of India, open limited laminectomy and discectomy proves to be a cost efficient method withno need of general anesthesia, early mobilization, basic instrument set requirement for spinal surgeries. The long-term outcomes are comparable to newer minimal invasive modalities and could be performed in smaller centres with basic facilities of C-arm or even portable X-ray machines. Also, the learning curve is comparatively shorter with better decompression achievable by thickened ligamentum flavum excision, when present.

Declarations

Author contribution

All the authors contributed equally to the conception of the study, development of the research design, the writing of the manuscript, research idea, and conducted the research. All authors reviewed and approved the final draft of the manuscript and take full responsibility for the content of this publication.

Ethics approval and Consent

Written informed consent was obtained from the patient/guardian. The patient's identity has been adequately anonymized. If anything related to the patient's identity is shown, adequate consent has been taken from the patient/relative/guardian.

Funding

No funding was received for the preparation of the manuscript

Conflict of Interest

The authors declare no conflicts of interest.

Disclosure

The authors hereby certify that the work shown here is genuine, original and has not been submitted anywhere, either in part or full.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):75-85
doi: 10.25305/unj.325159

Clinical study of management and outcomes in patients with degenerative cervical myelopathy treated with anterior cervical discectomy and fusion: an institutional experience and review of literature

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Received: 20 March 2025
Accepted: 07 May 2025

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Aim: This prospective observational study was done to evaluate the outcomes and management of patients with degenerative cervical myelopathy (DCM) treated with anterior cervical discectomy and fusion (ACDF).

Materials and methods: Our study included 80 patients with DCM admitted to a neurosurgical department between August 2013 and February 2023. Patients underwent ACDF surgery for single- or multi-level spinal canal stenosis. Demographic data, clinical features, and neurological examinations including assessments of limb power using the Medical Research Council Scale, sensory system function, and sphincter disturbance pre- and post-operatively were assessed. Pre- and post-operative neurological function was evaluated using the Nurick score, while post-operative outcomes were assessed using the Odom's criteria. The study population consisted mainly of males aged 51-60 years. Myelopathy was the most frequent presentation, with C5-C6 level being the most common level of fusion.

Results: ACDF surgery significantly improved neurological function, as evidenced by reduced pre-operative weakness and sensory dysfunction, and increased post-operative muscle strength. Minimal postoperative complications were observed.

Conclusions: These findings align with previous research, demonstrating ACDF as a safe and effective procedure for improving neurological function and quality of life in DCM patients. Limitations include sample size and study design, necessitating further research.

Key words: *degenerative cervical myelopathy; anterior cervical discectomy and fusion; myeloradiculopathy; Nurick score; Odom's criteria*

Introduction

Degenerative cervical myelopathy (DCM) represents the most prevalent cause of spinal cord impairment among adults globally [1]. This clinicopathological entity encompasses a broad spectrum of acquired and congenital conditions, including degenerative changes, hypertrophy, and calcification of the intervertebral discs, ligaments, and bony structures of the cervical spine. Notable examples include cervical spondylosis and ossification of the posterior longitudinal ligament (OPLL) [2,3]. These pathological processes result in stenosis of the cervical spinal canal, leading to chronic compression of the spinal cord and subsequent neurological and functional disabilities [4]. Cervical degenerative disc disease can be particularly debilitating, significantly compromising the quality of life. Magnetic Resonance Imaging (MRI) studies have demonstrated that many adults may present with cervical degenerative disc disease without exhibiting any clinical symptoms [5,6]. For symptomatic patients, conservative management is generally the initial preferred approach, with the majority responding positively to such treatment [7]. However, anterior cervical discectomy and fusion (ACDF) is recommended for patients who do not respond to conservative management [8-12]. In a well-selected cohort of patients characterized by younger age, a single-level soft disc, male gender, non-smokers, congruent radiological and clinical findings, and well-preserved neurological function, ACDF has been associated with favourable outcomes [13,14]. In this study, we evaluated the clinical presentations and outcomes following ACDF in patients with cervical degenerative disc disease across various age groups.

Aim and objectives

Aim:

To evaluate the outcomes and management of patients with degenerative cervical myelopathy treated with ACDF.

Objectives:

1. To determine the age- and sex-specific incidence of cervical degenerative disease in the study population.
2. To assess the clinical features, outcomes, and complications associated with cervical degenerative disease in patients treated with ACDF.
3. To compare pre-operative and post-operative Nurick scores and postoperative Odom's criteria outcomes.

Materials and methods

This prospective observational study was conducted at a single tertiary care hospital, focusing on patients admitted with degenerative cervical myelopathy to the Department of Neurosurgery from August 2013 to February 2023. Consent was obtained from all participants. A total of 80 patients were included in the study. The inclusion criteria encompassed patients presenting with cervical compressive myelopathy and myeloradiculopathy, affected at spinal levels between C3 and C7, with myelopathy secondary to cervical spinal canal stenosis involving the disc, patients experiencing persistent complaints unresponsive to conservative management for a minimum of three months, and those diagnosed with posterior osteophyte complex disease. Exclusion criteria included patients with cervical trauma, age less than 18 years, ongoing cervical infection and inflammation, and those presenting solely with radiculopathy. Baseline demographic data including age, sex, and medical history were collected. Clinical features, presenting symptoms, duration of symptoms, and neurological examination findings were documented. Pre-operative imaging studies, including X-ray of cervical spine antero-posterior and lateral views, MRI of cervical spine with whole spine screening were done. All surgeries were performed by experienced neurosurgeons using standardized techniques for ACDF. Intraoperative data, including the level of fusion, number of fusions and any intraoperative complications, were recorded. Clinical examinations were conducted at periodic intervals post-surgery (during the hospital stay, at the first follow-up during suture removal, and at three, six, and twelve months). During these examinations patients were asked whether their symptoms were the same, better, or worse post-surgery. At the six-month follow-up, patients were assessed based on Odom's criteria (excellent: no complaints and able to carry out physical activities; good: minimal persistence of preoperative symptoms but physical activities possible without significant interference; fair: relief of some preoperative symptoms with significant limitation in physical activities; poor: worsened or unchanged symptoms and signs) Patients were also assessed using the Nurick score (Grade 0: no root or cord symptoms; Grade I: root signs or symptoms with no cord involvement; Grade II: signs of cord involvement with normal gait; Grade III: gait abnormality but able to be employed; Grade IV: gait abnormality prevents employment; Grade V: able to ambulate only with assistance; Grade VI: chair-bound or bedridden). There were no cases of loss to follow-up.

Results

Table 1 summarises demographic details (age and gender distribution) and clinical characteristics of patients (clinical symptoms and duration of symptoms) diagnosed with cervical degenerative myelopathy.

The age distribution of patients reveals a predominant occurrence in the age group of 51-60 years, comprising 37 patients (46.25%) of the study population, followed by those aged 41-50 years with 28 patients (35%). Gender distribution shows a higher prevalence among males, accounting for 66 patients (82.50%). The duration of symptoms varied, with a notable proportion of patients, 42 (52.5%) reporting symptom durations between 6 to 12 months. Clinical symptoms observed in the patients include myelopathy, affecting 63 patients (78.75%) of the study population, and myeloradiculopathy, observed in 17 patients (21.25%).

Table 2 summarises the level of ACDF and the number of fusion procedures performed. It reveals that the majority of patients underwent single-level ACDF fusion surgery, with 67 patients receiving this intervention. Twelve patients underwent double-level fusion, and one patient underwent a three-level fusion in a single sitting.

Table 3 shows neurological examination preoperatively and postoperatively in the form of an assessment of limb power on the Medical Research Council (MRC) scale, sensory system examination, sphincter disturbances and surgical complications. Pre-operative power grades varied, with the majority, 39 patients (48.75%) falling into grade 4-, while post-operative assessments showed significant improvements, particularly in grades 4 and 4+. Sensory system evaluations revealed sensory affection in 28 patients (35%) pre-operatively, with a significant improvement noted post-operatively. Sphincter disturbance, specifically bladder involvement, was present in ten patients (12.50%) pre-operatively, of which two patients had improved sphincter control while the remaining eight patients (10%) showed no change post-operatively. Regarding complications, no intraoperative complications were reported, while three patients (6.3%) experienced immediate postoperative complications, primarily characterized by limb weakness and five patients (6.25%) experienced delayed postoperative complications in the form of non-improvement of symptoms of pain and spasticity. Complications such as severe blood loss, dysphagia, oesophageal perforation, infections, vocal cord palsy, and kyphosis, were not observed in this study.

Table 4 summarises Nurick score evaluation conducted pre-operatively and post-operatively and the outcome assessment based on Odom's criteria. Nurick score evaluation indicates improvements in neurological function following surgical intervention. The distribution of Nurick score post-operatively shows a decrease in scores compared to pre-operative assessments. Outcome assessment based on Odom's criteria demonstrates that the majority of patients, 31 (38.75%) achieved excellent outcomes, followed by a good outcome in 27 patients (33.75%), a fair outcome in 17 patients (21.25%) and a poor outcome in 05 patients (6.25%), reflecting positive outcomes in terms of neurological improvement post-surgery.

Figures 1-4 show pre-operative and post-operative radiological images in few of our patients.

This article contains some figures that are displayed in color online but in black and white in the print edition.

Table 1. Demographic and clinical characteristics of patients with cervical degenerative myelopathy

Characteristic	Number of patients	Percentage
Age distribution (years)		
21-30	2	2.5%
31-40	9	11.25%
41-50	28	35%
51-60	37	46.25%
61-70	4	5%
Gender distribution		
Male	66	82.50%
Female	14	17.50%
Duration of symptoms		
<6 months	29	36.25%
6-12 months	42	52.5%
>12 months	9	11.25%
Clinical symptoms		
Myelopathy	63	78.75%
Myeloradiculopathy	17	21.25%

Table 2. Surgical intervention details

Level of ACDF fusion	Number of patients
C3-C4	22
C4-C5	22
C5-C6	38
C6-C7	12
Number of fusions	
Single-level ACDF fusion	67
Double-level ACDF fusion	12
Three-level ACDF fusion	1

Note: ACDF - Anterior cervical discectomy and fusion

Table 3. Neurological examination pre- and post-operatively and complications

Evaluation	Number of patients (percentage)	
	Preoperative	Postoperative
Limb Power (MRC Scale)		
Grade 3	12 (15%)	6 (7.50%)
Grade 4-	39 (48.75%)	8 (10%)
Grade 4	29 (36.25%)	40 (50%)
Grade 4+	0	26 (32.50%)
Sensory system examination		
Affected	28 (35%)	16 (20%)
Non-affected	52 (65%)	64 (80%)
Sphincter disturbance		
Present	10 (12.50%)	8 (10%)
Absent	70 (87.50%)	72 (90%)
Surgical complications		
Intraoperative	0	
Immediate postoperative	3 (3.75%)	
Delayed postoperative	5 (6.25%)	

Note: MRC - Medical Research Council

Table 4. Nurick score evaluation preoperatively and postoperatively and Odom's criteria outcome assessment

Evaluation	Number of patients	
	Preoperative	Postoperative
Nurick score		
0	0	16
1	0	29
2	30	21
3	35	9
4	9	5
5	6	0
Odom's criteria outcome	Number of patients	
Excellent	31 (38.75%)	
Good	27 (33.75%)	
Fair	17 (21.25%)	
Poor	5 (6.25%)	

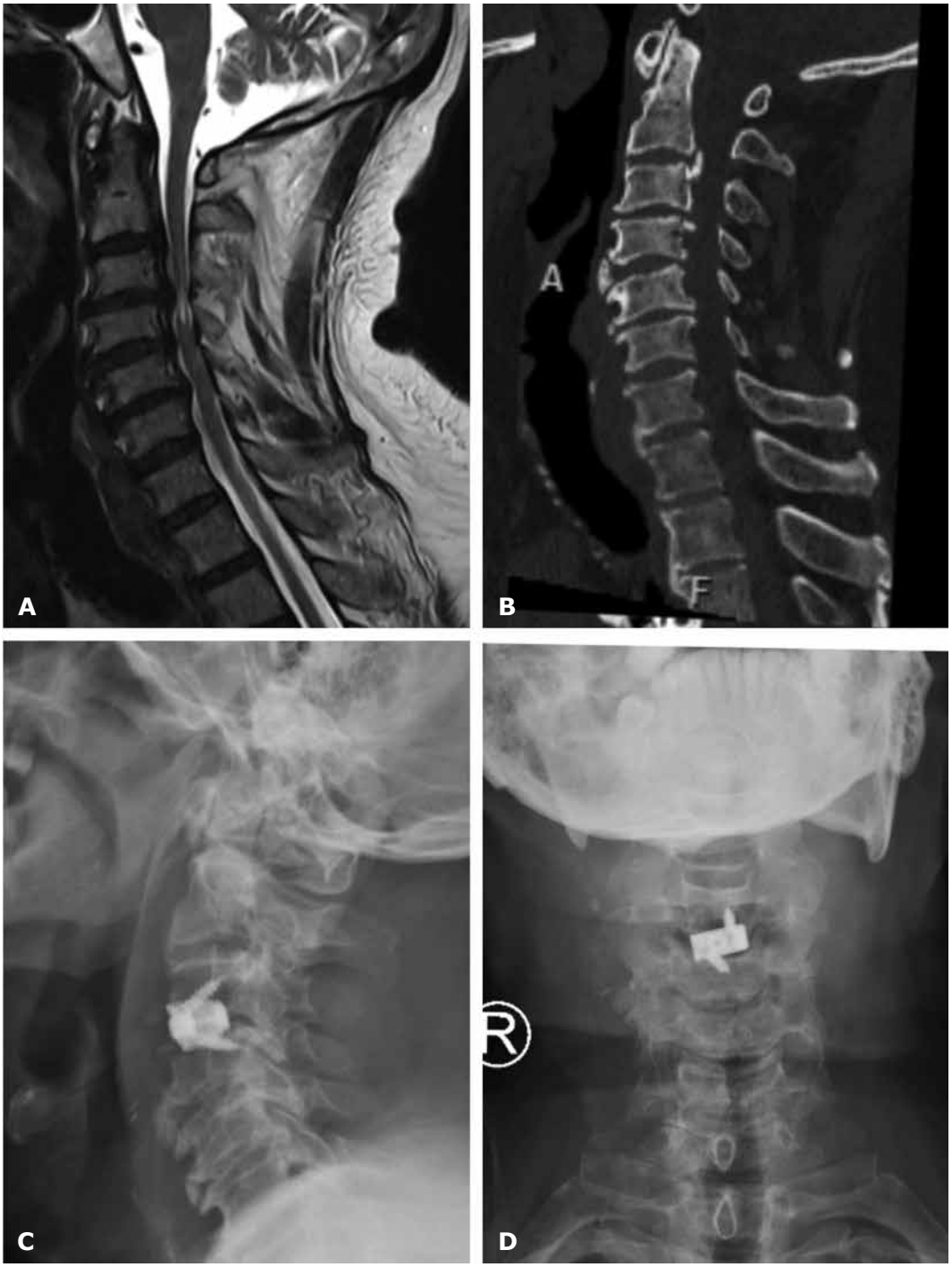

Fig. 1. A - Preoperative magnetic resonance imaging study of the cervical spine, (T2 weighted image, sagittal view) showing narrowing of central canal with cervical compressive myelopathy; B - Preoperative computed tomography imaging study of the cervical spine (sagittal view) showing osteophytes with narrowing of the central canal and straitening of the cervical lordosis; C - Postoperative radiographic imaging study of the cervical spine (sagittal view) showing the cage with screw *in situ*; D - Postoperative radiographic imaging study of the cervical spine (coronal view) showing the cage with screw *in situ*

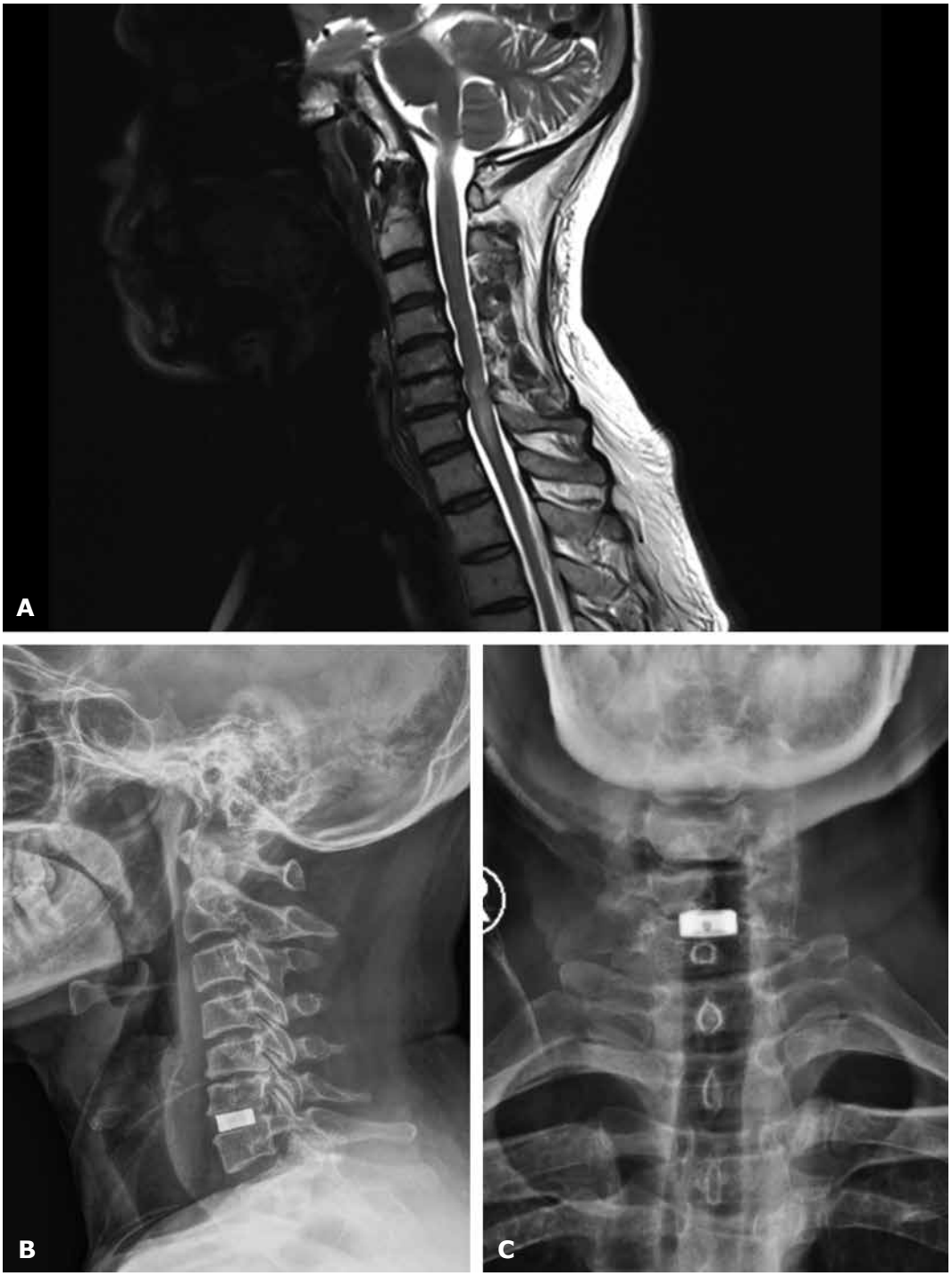

Fig. 2. A - Preoperative magnetic resonance imaging study of the cervical spine (T2 weighted image, sagittal view) showing cervical compressive myelopathy with disc osteophyte complex; B - Postoperative radiographic imaging study of the cervical spine (sagittal view) showing the cage *in situ*; C - Postoperative radiographic imaging study of the cervical spine (coronal view) showing the cage *in situ*

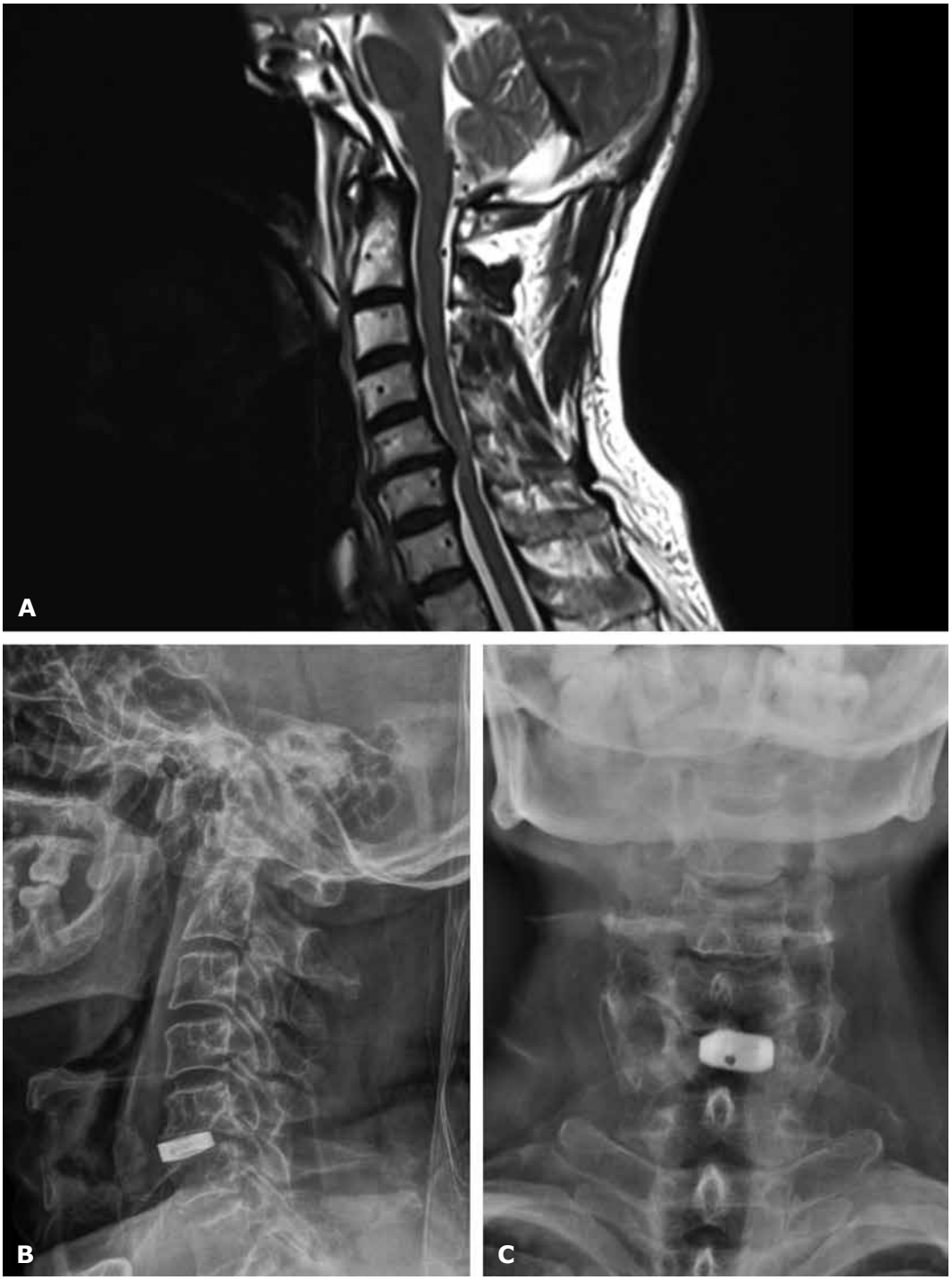

Fig. 3. A - Preoperative magnetic resonance imaging study of the cervical spine (T2 weighted image, sagittal view) showing cervical compressive myelopathy with disc osteophyte complex; B - Postoperative radiographic imaging study of the cervical spine (sagittal view) showing the cage *in situ*; C - Postoperative radiographic imaging study of the cervical spine (coronal view) showing the cage *in situ*

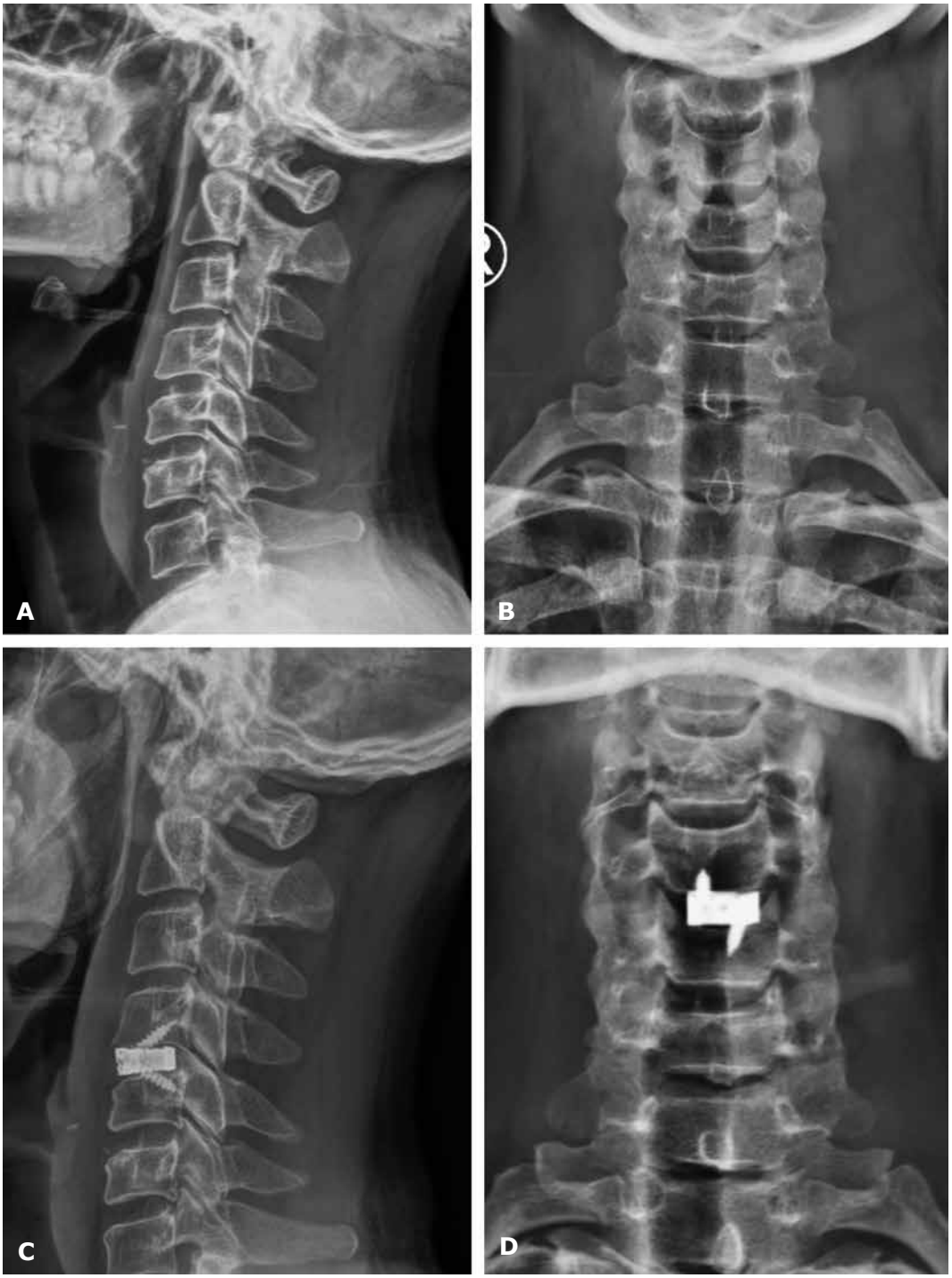

Fig. 4. A - Preoperative radiographic imaging study of the cervical spine (sagittal view) showing disc-osteophyte complex causing narrowing of the central canal; B - Preoperative radiographic imaging study of the cervical spine (coronal view); C - Postoperative radiographic imaging study of the cervical spine (sagittal view) showing the cage with screw *in situ*; D - Postoperative radiographic imaging study of the cervical spine (coronal view) showing the cage with screw *in situ*

Discussion

DCM is a significant condition that has garnered considerable research attention, with the aim of deepening our understanding of its pathophysiology and management. Key anatomical structures commonly affected by DCM include the vertebral body, intervertebral discs, posterior longitudinal ligament, ligamentum flavum, and uncovertebral joints. The clinical presentation of DCM may encompass motor, sensory, and/or sphincter dysfunction, often accompanied by notable signs such as Hoffman's sign and the inverted brachioradialis reflex. Diagnosis is primarily established through a clinical examination, supported by MRI evidence of cord compression [15]. The Nurick score remains a critical tool in evaluating neurological function both before and after surgical intervention. Surgical management is the cornerstone of DCM treatment, with approaches varying between anterior, posterior, or a combination of both. The anterior approach, including procedures such as corpectomy or ACDF, is generally preferred due to its association with fewer complications and a shorter hospital stay [3, 4]. Since the introduction of ACDF in 1958 [12] it has become one of the most frequently performed spinal surgeries [16]. ACDF is widely regarded as the gold standard for addressing degenerative cervical spine diseases due to its relatively low risk profile, reproducibility, and reliability [17]. A meta-analysis by Shahab Aldin Sattari et al. [18] found no significant differences between ACDF and posterior decompression in terms of functional outcomes at the one-year follow-up. However, ACDF was associated with less intraoperative bleeding, shorter hospital stays, and lower rates of surgical site infections and C5 palsy.

Our study focused on the outcomes of surgical interventions for degenerative cervical myelopathy/ myeloradiculopathy in 80 patients. The findings revealed a predominance of the condition in middle-aged males, with the most affected age group being 51-60 years, accounting for 46.25% of the cases, followed by the 41-50 years age group, representing 35% of the cases. Gender distribution demonstrated a higher prevalence among males (82.50%) compared to females (17.50%). These demographic details are consistent with the studies conducted by Shrikhande N.N. et al. [19] and Saravanan A et al. [20]. Several clinical syndromes are associated with cervical disc disease including cervical spondylotic myelopathy/ myeloradiculopathy, cervical radiculopathy, and neck pain syndromes. Our study excluded cases involving only radiculopathy or neck pain syndrome, focusing primarily on patients presenting with myelopathy (78.75%) or mixed symptoms of myeloradiculopathy (21.25%), aligning with the observations of Shrikhande N.N. et al. [19] and Hwang et al. [21]. Furthermore, approximately 52.5% of the patients reported symptoms lasting 6 to 12 months, similar to findings by Suri A. et al. [22]. However, Ramesh et al. [23] highlighted a significant proportion of patients experiencing symptoms for over 12 months, underscoring the importance of early detection and prompt intervention to optimize outcomes and prevent further neurological deterioration.

In terms of surgical procedures, the most frequently observed single-level of fusion was at C5-C6, occurring in 38 cases, consistent with Shrikhande N.N. et al. [19] and Saravanan A. et al. [20]. Double-level fusion surgery was performed on 12 patients, with only one patient undergoing three-level fusion in a single sitting, further aligning with the findings of Shrikhande N.N. et al. [19] and Saravanan A. et al. [20], indicating that three-level fusion is less frequently performed.

Our analysis revealed significant improvements in neurological function following surgery. Pre-operative weakness Grade 4- MRC scale decreased substantially from 48.75% to 10% postoperatively, accompanied by a notable increase in excellent muscle strength Grade 4+ MRC scale from 0% to 32.50%. Additionally, pre-operative sensory dysfunction decreased from 35% to 20% post-surgery. The rate of sphincter disturbances remained consistent at around 10% pre- and post-operatively, similar to the findings of Shrikhande N.N. et al. [19] who reported no significant improvement in this area. Although the study was limited by sample size and design, the minimal postoperative surgical complications (3.75% immediate, 6.25% delayed) suggest ACDF as a safe and effective procedure for improving neurological function in DCM patients. The postoperative weakness was also improved gradually in all the patients. In contrast, studies by Mastronardi L. et al. [24] and Choi S.H. et al. [25] reported various complications, including severe blood loss, dysphagia, oesophageal perforation, infections, vocal cord palsy, and kyphosis. None of these were observed in our study. This absence of severe complications suggests successful surgical management and perioperative care, contributing to favourable outcomes.

The mean preoperative Nurick score, indicating the severity of impairment, was 2.57. However, this score improved significantly post-surgery, dropping to 1.12 on average. Consistent with these findings, studies by Gupta A. et al. [26] demonstrated significant reductions in Nurick scores after surgery, further supporting the notion that ACDF intervention can lead to reduced neurological impairment and enhanced functional abilities in DCM patients. The decrease in postoperative Nurick scores across these studies suggests that surgical treatment plays a crucial role in enhancing patients' quality of life and functional abilities. Furthermore, analysis using Odom's criteria at six months revealed positive outcomes for a substantial portion of patients. Nearly 40% (38.75%) achieved an excellent outcome, with good and fair outcomes were observed in an additional 55% of patients. These results are comparable to previous research by Hassan M. et al. [27] and Saravanan A. et al. [20], who also reported high rates of positive outcomes following ACDF surgery for DCM. While limitations including sample size and study design necessitate further research involving larger, controlled studies, the current findings provide promising evidence of the effectiveness of ACDF surgery in improving outcomes for DCM patients. Additionally, the study by Long Tang et al. [28] suggests that day-surgery ACDF may offer safety and early efficacy comparable to traditional inpatient procedures, presenting a promising alternative for eligible patients. This research highlights the potential of ACDF surgery to improve neurological function and functional abilities, ultimately enhancing patients' quality of life.

Conclusion

Our study investigated the effectiveness of ACDF surgery in managing DCM in 80 patients. Our analysis revealed a predominance of the condition in middle-aged males, with the most frequent surgical level being C5-C6. Significantly, ACDF surgery resulted in substantial improvements in neurological function, as evidenced by reductions in pre-operative weakness and sensory dysfunction, along with a notable increase in excellent muscle strength. Furthermore, the minimal postoperative complications observed suggest ACDF as a safe and effective procedure for patients with DCM. The study also highlights the importance of early intervention. These findings align with previous research demonstrating positive outcomes following ACDF surgery. The decrease in Nurick scores across our study and others highlights the potential of ACDF intervention to improve neurological function, functional abilities, and ultimately, patient quality of life in DCM patients. While limitations including sample size and study design necessitate further research with larger, controlled studies, the current results provide promising evidence for the effectiveness of ACDF surgery in managing DCM.

Declarations

Disclosure

Hereby it is stated that the manuscript has been read and approved by all the authors. Each author believes affirms that the manuscript represents honest work and confirms that the information has not been published or submitted elsewhere in any form.

Consent

Informed consent was obtained from all participants.

Conflict of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Funding

The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

Author's contribution

All authors contributed equally to the manuscript and approved the final version of the manuscript.

Research ethics

This study was observational, focusing on patients with Degenerative cervical myelopathy (DCM). All participants received the same standard treatment. The study aimed to evaluate the outcomes and management of patients with degenerative cervical myelopathy treated with ACDF. Objectives were to determine the age- and sex-specific incidence of cervical degenerative disease in the study population, to assess the clinical features, outcomes, and complications associated with cervical degenerative disease in patients treated with ACDF and to compare pre-operative and post-operative Nurick scores as well as postoperative Odom's criteria outcomes without any deviation from standard clinical practice.

Given that the study was purely observational and did not involve any experimental procedures, manipulation of variables, or assignment of participants to different treatment groups, it was deemed to fall under the category of research that does not require IRB approval. All data were collected in a manner consistent with routine clinical practice, ensuring that patient care was not impacted in any way by the study. Patient confidentiality and ethical standards were strictly maintained throughout the study. No identifiable patient information was collected, and all data were anonymized to protect the privacy of the participants.

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Original article

Ukrainian Neurosurgical Journal. 2025;31(2):86-92
doi: 10.25305/unj.326745

Diagnosis and endoscopic treatment of suprasellar arachnoid cysts in pediatric patients: A case series and analysis of clinical observations

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Received: 11 April 2025
Accepted: 09 May 2025

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Suprasellar arachnoid cysts are rare entities, accounting for approximately 20% of all intracranial arachnoid cysts.

Objective: To evaluate the efficacy of endoscopic ventriculocystostomy and endoscopic ventriculocystocisternostomy in the treatmentof children with suprasellar arachnoid cysts.

Materials and Methods: Between 2016 and 2023, 29 children with suprasellar arachnoid cysts were treated at the Romodanov Institute of Neurosurgery, National Academy of Medical Sciences of Ukraine. The cohort included 18 boys (62%) and 11 girls (38%), with ages ranging from 4 months to 17 years (mean age – 2.8 years). Depending on the surgical technique used, patients were divided into two groups: Group 1 (n=19) underwent endoscopic ventriculocystostomy, and Group 2 (n=10) underwent endoscopic ventriculocystocisternostomy.

Results: The effectiveness of both procedures was confirmed by clinical and radiological assessments. Postoperative hospital stay ranged from 6 to 18 days in Group 1 (mean – 10.2±3.1 days) and from 7 to 17 days in Group 2 (mean – 11.3±3.8 days; p=0.411). The duration of surgery ranged from 25 to 70 minutes (mean – 48.4±13.0 min) in Group 1 and from 45 to 70 minutes (mean – 52.5±8.2 min) in Group 2 (p=0.378). In the early postoperative period, full recovery was observed in 6 patients (33%) in Group 1 and in 2 patients (20%) in Group 2. In the long-term follow-up period, recovery rates were 63% and 70%, respectively. No mortality or disease progression was reported, and no patient required permanent shunt placement. Recurrence occurred in one patient from Group 1.

Conclusions: The analysis of clinical and radiological data demonstrates the effectiveness of both ventriculocystostomy and ventriculocystocisternostomy. Both methods may be recommended for the treatment of suprasellar arachnoid cysts in children due to their minimally invasive nature, low postoperative complication rates, and absence of mortality.

Keywords: *arachnoid cyst; endoscopy; shunting; children*

The first reports of suprasellar arachnoid cysts (ACs) date back to 1935 and are associated with the name of A. Barlow [1]. He was the first to attempt surgical removal of such a cyst, although the patient died on the second postoperative day. In 1960, V. Cassinari reported eight cases of cysts located in the chiasmal-sellar region [2]. In 1965, R. Bernard described a suprasellar AC in a pediatric patient [3].

In adults, suprasellar cysts account for only 9% of all ACs, while in pediatric populations, their prevalence reaches 21% [10, 11]. The most common location of ACs is within the lateral fissure of the brain, where they partially or completely fill the middle cranial fossa (MCF), constituting the majority of intracranial ACs [5]. A less frequent subtype is the suprasellar AC, situated within the suprasellar cistern, projecting into the third ventricle [4, 6]. Suprasellar AC is non-neoplastic, congenital cavity filled with cerebrospinal fluid (CSF) and lined by arachnoid membrane. They are thought to arise due to an anomaly of the Liliequist membrane or cystic dilatation of the interpeduncular cistern [22]. The precise etiology of suprasellar ACs remains uncertain; however, recent data suggest that they may result from a valvular mechanism at the site where the basilar artery penetrates the prepontine arachnoid membrane [7, 8].

The clinical presentation of ACs is highly variable and may be asymptomatic. Most cysts remain stable over time, but a subset may gradually enlarge and provoke clinical symptoms [9]. Current evidence indicates that in children under the age of 4, ACs are frequently asymptomatic, necessitating careful monitoring for potential growth [12].

As cysts enlarge, patients may develop neurological symptoms due to compression of adjacent structures and/or the onset of hydrocephalus. This may manifest clinically as vomiting, seizures, headaches, macrocrania, endocrine disturbances, ataxia, developmental delay, visual deficits, or oculomotor dysfunctions [13, 14].

Obstructive hydrocephalus may occur as a result of cyst-induced compression of the foramen of Monro or

the cerebral aqueduct, thereby impairing CSF outflow. Endocrine dysfunction may arise from compression of the pituitary stalk, and visual disturbances may be caused by pressure on the optic nerve and surrounding structures. Among clinical manifestations, headache is the most prevalent symptom, occurring in 66% of patients [15]. Studies have shown that signs of elevated intracranial pressure are the most common symptoms in adults, whereas pediatric cases are more frequently characterized by delayed psychomotor development and macrocephaly [17]. Due to the potential emergence of these clinical symptoms in larger cysts, surgical treatment is considered a preferable approach over observation. Several surgical techniques are available for the treatment of such cysts: microsurgical fenestration via open craniotomy, cystoperitoneal shunting, and endoscopic treatment through ventriculocystostomy (VCS) or ventriculocystocisterno- stomy (VCCS) [18]. In VCS, an endoscope and instruments are used to fenestrate only the apical membrane of the cyst, whereas in VCCS, the same endoscopic approach is applied: the apical membrane is fenestrated, and the endoscope is advanced into the cyst cavity to penetrate through the cyst to the inferior membrane located in the interpeduncular and prepontine cisterns, where additional fenestration is performed to enable communication between the cyst and the basal cisterns [4].

There are no standardized preoperative criteria for selecting each surgical method, which likely explains the variability in technique preference among institutions and surgeons. Given the rarity of these cysts, no single center has accumulated a sufficiently large number of cases to conduct a thorough evaluation of surgical outcomes. Furthermore, despite the increasing rate of diagnosis of suprasellar arachnoid cysts in the pediatric population, only a limited number of studies have examined the differences in surgical outcomes across various approaches.

Objective: To evaluate the effectiveness of endoscopic ventriculocystostomyc and endoscopic ventriculocystocisternosto-my in the treatment of pediatric patients with suprasellar arachnoid cysts.

Materials and methods

Inclusion criteria:

Patients under 18 years of age;

Presence of symptoms associated with suprasellar arachnoid cysts AC;

Availability of informed consent from the patient's parents to participate in the study;

Use of endoscopic surgical techniques for the treatment of suprasellar AC (endoscopic ventriculocystostomy VCS or ventriculocystocisternostomy VCCS).

Study Participants

All children under the age of 18 who underwent endoscopic surgical treatment for suprasellar AC were identified through a systematic review of case histories at the Romodanov Institute of Neurosurgery of the National Academy of Medical Sciences of Ukraine. For the purposes of this study, patient inpatient and outpatient records were reviewed, including operative reports, preoperative and postoperative assessments based on instrumental diagnostic methods, surgical technique employed, postoperative course, and clinical follow-up data.

All pediatric patients underwent preoperative magnetic resonance imaging (MRI) of the brain, including thin-slice sequences (sT2W_TSE, T2W_TSE, CSF-drive). Special attention was paid to cyst size, presence of hydrocephalus, upward displacement of the floor of the third ventricle, posterior displacement of the brainstem, and vertical displacement of the optic chiasm and mammillary bodies ***(Fig. 1)***.

Neurosonography was performed at different stages of treatment in children under the age of one year. In urgent cases and during the postoperative period, spiral computed tomography of the brain was conducted.

Ventricular system enlargement was observed in all examined cases. The diagnosis of "obstructive hydrocephalus" was confirmed in all 29 (100%) patients. The presence of hydrocephalus enabled the use of endoscopic surgical techniques. For diagnosis, determination of indications, planning of the type/ course of intervention, and postoperative monitoring, neurosonography was performed in 18 cases (62%), spiral CT of the brain in 17 (41%), including 5 for diagnostic verification and 12 within the first 24 hours after surgery, and brain MRI in all 29 patients (100%).

Between 2016 and 2023, twenty-nine children were surgically treated at the Romodanov Institute of Neurosurgery of the National Academy of Medical Sciences of Ukraine. Among them, 18 (62%) were boys and 11 (38%) were girls. The age at the time of the first operation ranged from 4 months to 17 years (mean age – 2.8 years).

The most common symptoms included macrocephaly (in 55% of patients) and signs of intracranial hypertension (in 41%). Developmental delay was observed in 7 patients (24%). Oculomotor disorders were noted in 5 cases (17%), and decreased visual acuity in 3 (24%).

All patients underwent surgery under general anesthesia using an exclusively endoscopic approach. Patients were positioned supine. The burr hole was made 1 cm anterior to the coronal suture and 3 cm lateral to the midline. A rigid endoscope (Lotta series, Karl Storz, Germany) with three access ports was used for the operations ***(Fig. 2)***.

A dural incision was performed. The endoscopic trocar was introduced perpendicularly to the skull surface, which facilitated access to the right lateral ventricle. The apical surface of the cyst wall, which was obstructing the foramen of Monro, was visualized. The surgeon used clearly identifiable anatomical landmarks for orientation. With the aid of bipolar electrocoagulation, ventriculostomy forceps, and micro-scissors, a stoma was created between the lateral ventricle and the cyst cavity (endoscopic cystocisternostomy – group 1). After the initial opening of the proximal cyst wall in group 2, the endoscope was advanced toward the distal (inferior) aspect of the cyst wall to perform fenestration (stoma formation). This technique allows communication between the cyst and the CSF pathways, as well as connection between the lateral ventricle and the interpeduncular cistern, thereby facilitating effective treatment.

This article contains some figures that are displayed in color online but in black and white in the print edition.

The endoscopic anatomy and procedural steps of the endoscopic intervention are illustrated in ***Fig. 3***.

All surgeries were primary interventions, i.e., performed without prior use of microsurgical techniques for treating suprasellar cysts. One patient had a history of ventriculoperitoneal shunt placement performed at another medical facility.

According to the method of endoscopic surgical treatment, patients were divided into two groups: Group 1 (n = 19) underwent endoscopic VCS, Group 2 (n = 10) – endoscopic VCCS.

The diagnosis of AC in all patients was established based on clinical and instrumental diagnostic findings.

Clinical outcomes assessed included symptoms present at the time of initial diagnosis, during postoperative follow-up, or prior to repeat surgery. These were categorized as resolved, improved, unchanged, or worsened (according to the description of the patient or their parents).

Changes in cyst size were analyzed based on MRI data obtained preoperatively and postoperatively (on the 90th day after surgery). Three dimensions (length, height, width) were measured and converted into a calculated volume (cm^3).

Follow-up duration ranged from 12 to 48 months, with a mean of 22 months.

Quality of life in the preoperative, early postoperative, and late postoperative periods was assessed using the Lansky Performance Scale ***(Table 1)***.

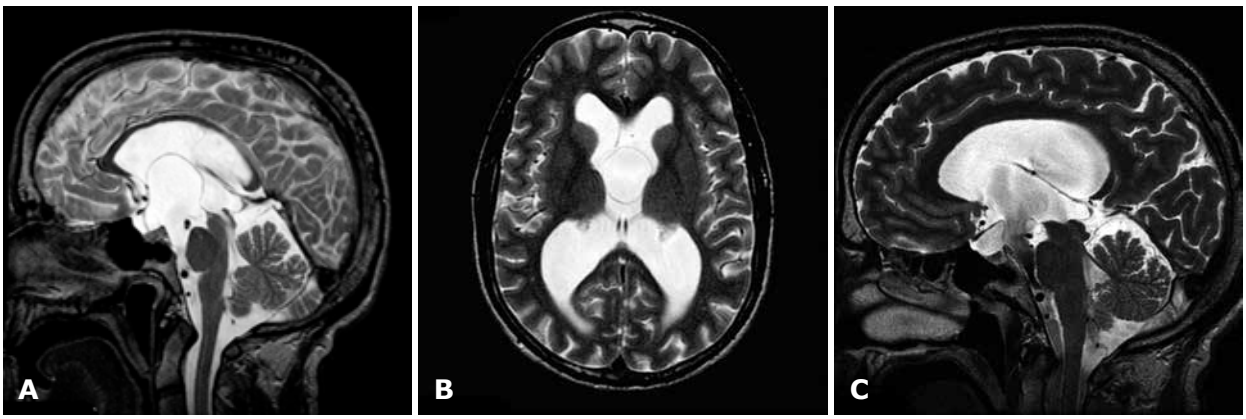

Fig. 1. MRI of the ирain. Signs of a suprasellar arachnoid cyst: A – T2-weighted sagittal images; B – T2-weighted axial images; C – postoperative condition after endoscopic VCS in CSF-drive mode

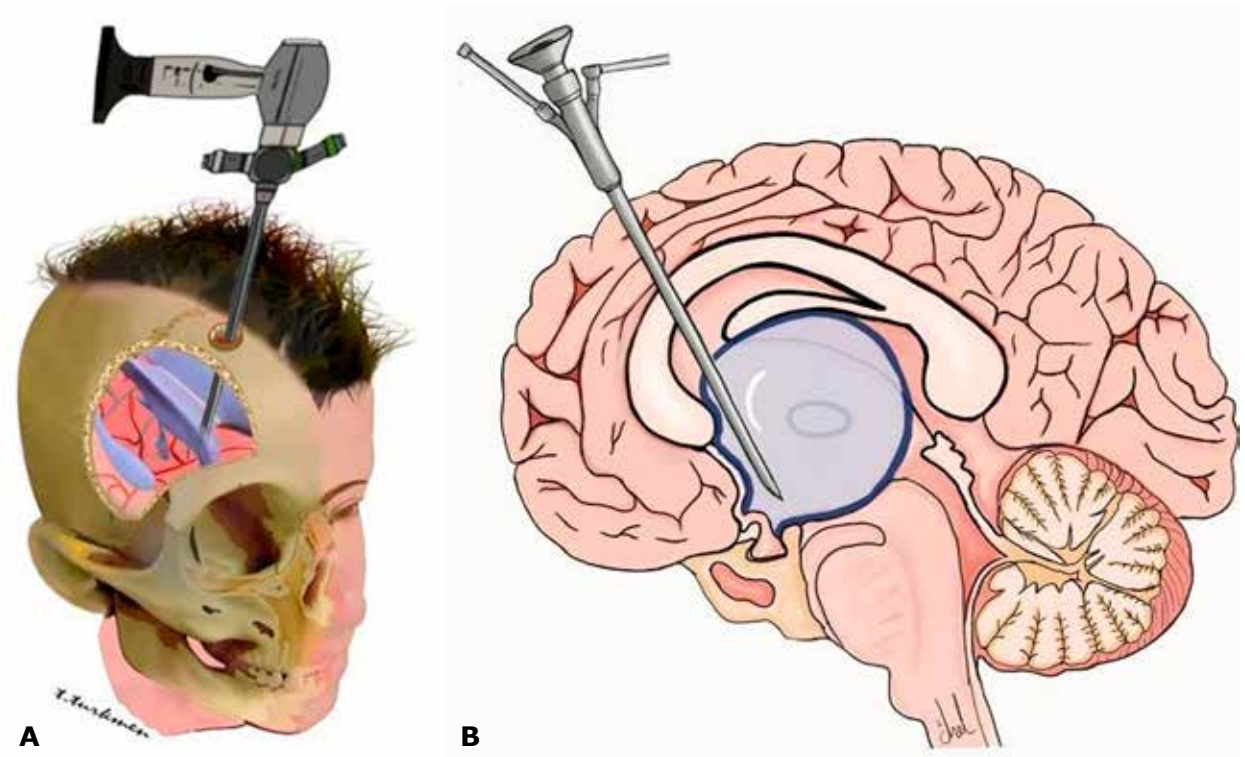

Fig. 2. Illustrative depiction of neuroendoscopic surgical technique: A – schematic representation of the trephination point; B – endoscopic view of a ventriculocystocisternostomy in a patient with a giant suprasellar arachnoid cyst [19]

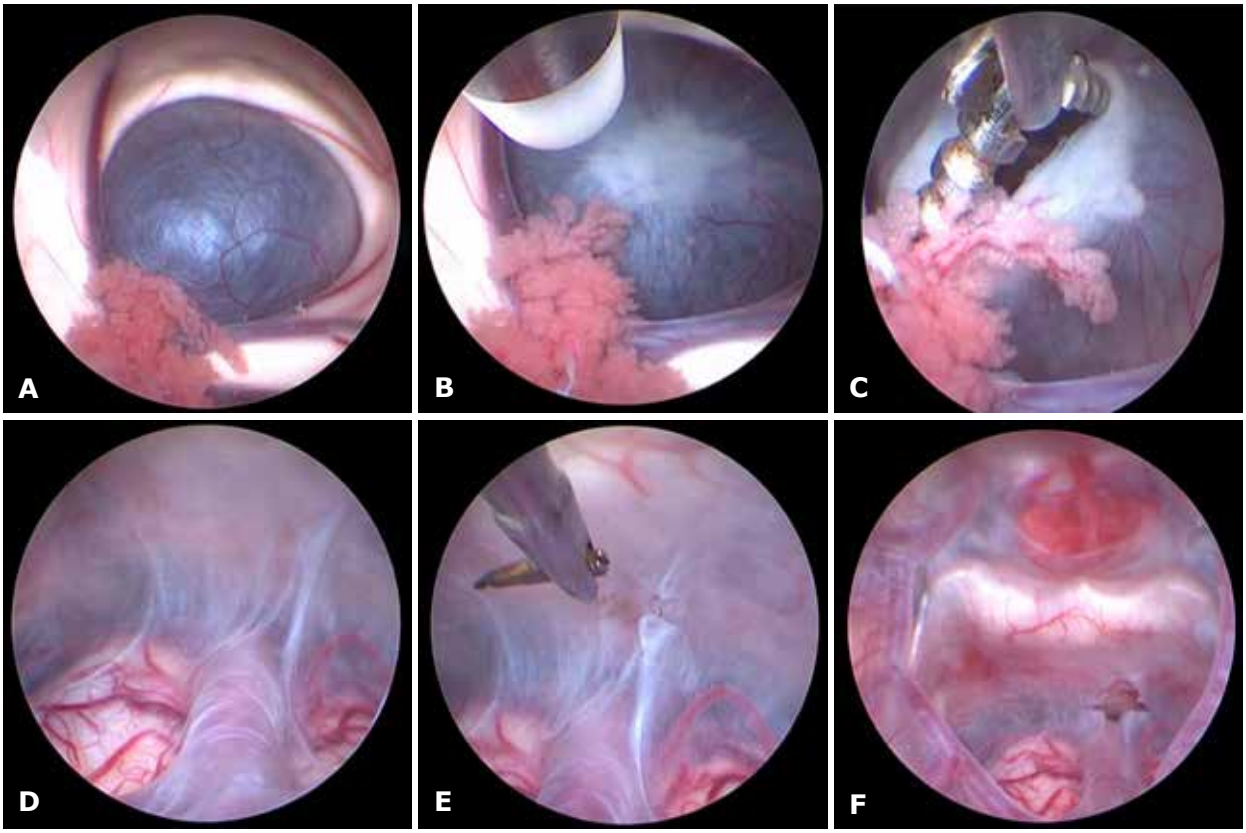

Fig. 3. Intraoperative anatomy during endoscopic VCS and endoscopic VCCS:
A – intraoperative endoscopic view of the cyst;
B, C – operative stages of stoma formation between the ventricular system of the brain and the suprasellar cyst (endoscopic VCS);
D – intraoperative endoscopic view of the internal surface of the cyst wall, basilar artery, and brainstem;
E – stage of stoma formation between the cyst cavity and the interpeduncular cistern (endoscopic VCCS);
F – view of the completed stoma, pituitary gland and infundibulum, basilar artery, cranial nerves, and dorsum sellae

Table 1. Lansky scale (for patients under 16 years of age)

Description	Condition assessment, score
Fully active, normal	100
Minor limitations in physical activity	90
Active, but tires quickly	80
Noticeable limitations in activity, spends less time on play	70
Minimal participation in active play, engaged in quiet activities	60
Gets dressed, but spends most of the time lying down; does not engage in active play, can participate in quiet activities	50
Spends most of the time in bed, but can participate in quiet activities	40
Sleeps most of the time, requires assistance even with the calmest activities	30
Sleeps most of the time, capable only of passive engagement	20
Confined to bed	10
Moribund (near death)	0

Study design

This study was conducted as a retrospective analysis.

Statistical analysis

Data processing and analysis were performed using descriptive statistics, univariate and multivariate analyses, as well as survival estimation methods. The statistical software used was Statistica v.10 (StatSoft® Inc., USA, license No. STA862D175437Q). The Shapiro–Wilk test was applied to assess the normality of quantitative variable distributions. Parametric statistics were used for normally distributed data. The mean (*M*), standard error of the mean (*m*), and standard deviation (*SD*) were calculated. Comparisons were made using Student's t-test for independent samples. For ordinal data (e.g., Lansky scale), the median (*Me*) and interquartile range (25;75%) were calculated.

Statistical significance of differences in categorical data was assessed using the χ^2 test (Fisher's exact test) and the Mann–Whitney U test for ordinal data. Differences between groups were considered statistically significant at P<0.05 (error risk <5%).

Results and discussion

The duration of postoperative hospital stay was comparable between the two groups: in Group 1, it ranged from 6 to 18 days (mean (10.2±3.1) days); in Group 2, from 7 to 17 days (mean (11.3±3.8) days, P=0.411).

No complications were observed in Group 1. In contrast, two (6%) surgical complications occurred in Group 2. One (3%) case of intraoperative arterial bleeding during VCCS was reported. The bleeding was minor, did not require interruption of the procedure, and resolved spontaneously within a few minutes after irrigation, with no postoperative consequences. In the postoperative period, one (3%) case of wound cerebrospinal fluid (CSF) leakage was recorded following VCCS.

Post-treatment outcomes indicated a reduction in cyst size ***(Table 2)***.

In Group 1, during the early postoperative period, cyst size showed no significant change (10–30% reduction compared to preoperative measurements) in 5 cases (26.3%). A mild reduction was observed in another 5 cases (26.3%), while a marked reduction (51–100%) was noted in 9 cases (47.4%). In Group 2, cyst size remained unchanged in 1 case (10%), decreased by 31–50% in 4 cases (40%), and by 51–100% in 5 cases (50%).

A recurrence was documented in one case in Group 1. During reoperation, intraoperative endoscopic evaluation revealed closure of the stoma. The child underwent repeat endoscopic VCS twice due to cyst recurrence in the postoperative period. A decision was made to perform endoscopic VCCS as a subsequent intervention. No disease progression was observed during the follow-up period.

The duration of surgical intervention ranged from 25 to 70 minutes, averaging (48.4±13.0) minutes in Group 1 and from 45 to 70 minutes in Group 2, with a mean duration of (52.5±8.2) minutes (p=0.378).

No deterioration in condition or emergence of new neurological deficits was observed in either group during the early or late postoperative periods.

The general preoperative condition of the children in both groups, as assessed by the Lansky scale, averaged 80 (70; 90) points (p=0.924).

In the early postoperative period, quality of life improved: in Group 1, the median score was 90 (80;100), and in Group 2, it was 90 (80;90) (p=0.848). In the late postoperative period, both groups reported a median score of 100 (90;100) (p=0.659), indicating comparable outcomes between the groups.

Complete recovery (absence of complaints and regression of preoperative symptoms) in the early postoperative period was achieved in 6 (33%) patients in Group 1 and in 2 (20%) patients in Group 2 (p=0.507). In the late postoperative period, full recovery was observed in 12 (63%) and 7 (70%) patients, respectively (p=0.712). The improvement in quality of life over time was statistically significant in both groups (p=0.001).

Effective treatment of suprasellar ACs in pediatric patients remains a topic of ongoing discussion among pediatric neurosurgeons. Notably, compared to adults, children are twice as likely to present with such cysts, necessitating research to determine the most appropriate surgical approach. As pediatric neurosurgery has advanced over the past decade, there has been a growing preference for endoscopic treatment over traditional microsurgical fenestration via craniotomy and/or shunting. Despite the evolution of this technique, few studies have been conducted, and most have involved small sample sizes, likely due to single-center limitations and the rarity of such cases. Consequently, only a limited number of institutions have had the capacity to compare all surgical approaches comprehensively and draw definitive conclusions.

Since suprasellar ACs are typically asymptomatic, the majority of patients opt against surgery in favor of conservative management and observation. However, surgical intervention has been justified in patients presenting with pronounced clinical symptoms and a high risk of complications, necessitating operative treatment.

Table 2. Tomographic results of surgical treatment of suprasellar arachnoid cysts in the early postoperative period

Group	No Change	No Significant Change	Slight Reduction in Cyst Size	Significant Reduction in Cyst Siz	Total
1-st (n=19)	0	5 (26,3%)	5 (26,3%)	9 (47,4%)	19 (100,0%)
2-nd (n=10)	0	1 (10,0%)	4 (40,0%)	5 (50,0%)	10 (100,0%)
Total		6 (20,7%)	9 (31,0%)	14 (48,3%)	29 (100,0%)

Note: no change refers to a cyst size reduction of 0–10%; insignificant change denotes a reduction of 11–30%; mild reduction implies a decrease of 31–50%; marked reduction indicates a size decrease of 51–100%. The difference between the groups was statistically insignificant ($p(\chi^2)=0.536$).

Long-term outcomes are typically evaluated based on symptom resolution, instrumental confirmation of cyst size reduction, and the need for additional surgical interventions (including repeated endoscopic procedures or shunt system revisions). Each of the three primary treatment approaches—fenestration via open craniotomy, cystoperitoneal shunting, and endoscopic fenestration—has distinct advantages and disadvantages. According to current scientific literature, endoscopic fenestration is considered the most effective treatment for arachnoid cysts.

Open cyst fenestration is generally not recommended as the optimal treatment for ACs due to the risks and complications associated with craniotomy. Nevertheless, one of its advantages lies in the potential to achieve shunt independence [17, 20]. However, this approach is often viewed as overly aggressive for treating symptomatic ACs [20,21]. Furthermore, open surgical procedures are frequently associated with high recurrence rates and limited effectiveness [17, 20, 21]. Complications following open fenestration may include meningitis, subdural hematoma, seizures, hemiparesis, and oculomotor nerve palsy [20, 21].

Given the relative risks, complications, and outcomes of microsurgical cyst wall fenestration, this method is generally recommended less frequently than alternative treatment options. Cystoperitoneal or ventriculoperitoneal shunting serves as an alternative to microsurgical fenestration. Shunting is often more effective than craniotomy-based fenestration [17, 20, 22]; however, it may lead to lifelong shunt dependency [17, 20] and frequently necessitates revision surgeries [22, 23].

The complication rate associated with shunting is lower than that of open fenestration [17, 23], which is why it is often preferred over craniotomy [20, 23].

Given the potential complications related to both microsurgical fenestration via craniotomy and shunting, in comparison to endoscopic treatment, most studies conclude that endoscopic surgery (either VCS or VCCS) is the superior method for treating sellar ACs in pediatric patients. Although endoscopic surgical management of this condition was previously considered limited, such procedures are now increasingly performed.

Among endoscopic approaches, most studies favor VCCS over VCS due to better clinical outcomes. This preference is attributed to the lower failure rate of VCCS compared to VCS. Patients undergoing VCCS are less likely to require reoperation, thus facing a reduced risk of infection and other postoperative complications associated with repeated neurosurgical interventions. Additionally, VCCS offers the highest probability of complete symptom resolution in affected patients [23].

However, numerous studies report an increased risk of anatomical damage during VCCS due to the close proximity of cranial nerves and the basilar artery. This is because the surgical approach requires navigating through the cyst into the interpeduncular and prepontine cisterns, whereas VCS only involves opening the apical membrane and entering the cyst cavity.

Conclusions

The endoscopic technique can be recommended for the treatment of suprasellar arachnoid cysts in pediatric patients, as it is effective, minimally invasive, and associated with low postoperative complication and mortality rates. According to our data, both procedures—ventriculocystostomy and ventriculocystocisternostomy—demonstrated nearly equivalent clinical and radiological outcomes.

The detection of stomal reocclusion following VCS in cases of cyst recurrence highlights the importance of performing VCCS during the initial surgery to prevent recurrence.

Endoscopic methods for treating symptomatic suprasellar arachnoid cysts enable sustained regression of clinical symptoms with minimal risk of reoperation.

In our view, the observed complications are more closely related to anatomical variations rather than the choice of surgical method. However, considering both current literature and our findings, there is a significant difference in the long-term recurrence rates between VCS and VCCS. We conclude that VCCS should be considered the procedure of choice in the treatment of these cases.

Disclosure

Conflict of interest

The authors declare no conflict of interest.

Ethical standards

All procedures performed on patients in this study were in accordance with the ethical standards of the institutional and national research ethics committees and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Funding

This research received no sponsorship.

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