



THE ROLE OF EXPANDABLE CAGES FOR VERTEBRAL BODY REPLACEMENT IN SURGICAL TREATMENT OF PATIENTS WITH THORACIC AND LUMBAR SPINE INJURIES: A SYSTEMATIC REVIEW

S.D. Shuvalov, A.E. Shulga, S.P. Bazhanov, V.V. Ostrovskij, V.S. Tolkachev

Saratov State Medical University n.a V.I. Razumovsky, Saratov, Russia

Objective. To perform a systematic analysis of contemporary scientific data characterizing the clinical effectiveness of expandable implants for vertebral body replacement in the complex surgical treatment of patients with thoracic and lumbar spine injuries.

Material and Methods. The search for scientific sources was carried out in accordance with the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions and the PRISMA principles in the Cochrane Library, PubMed and Medline databases for the period 2015–2025 a total of 19 studies on the radiological and functional outcomes of the surgeries involving implantation of expandable spinal cages for thoracic and lumbar spine injuries were analyzed.

Results. The technologies for spinal surgery have been developing rapidly over the recent decades. The improvements in minimally invasive techniques have required modifications to implants including those for anterior support spinal fusion. The implants of transformable geometry which allow the replacement of spinal defects that significantly exceed their original dimensions are of particular interest. The contemporary expandable spinal cages vary in the material they are made from and their transformation mechanisms. The literature describes successful cases of their use in thoracic and lumbar spine injuries. The authors demonstrate favorable surgical outcomes using combinations of screw-assisted fusion and interbody implants.

Conclusion. Expandable spinal cages feature a wide range of applications in the treatment of spinal injuries. The advent of vertical lift mechanisms in intervertebral implants has led to a trend towards modifying surgical techniques, particularly the sequence of intervention stages. Despite differences in approaches, specialists favor minimally invasive implant placement, with radiographic and functional results showing no significant differences.

Key Words: traumatic vertebral fracture; corpectomy; spinal reconstruction; spondylosynthesis; expandable implant.

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Injuries to the thoracic and lumbar vertebrae represent up to 70% of all spinal injuries [1]. The thoracolumbar spine (T11–L2) is most commonly affected because of its anatomical location and the characteristics of sagittal biomechanics [2, 3]. The steady growth in the number of patients is attributed to urbanization in metropolises, the increasing pace of life, and the rise in local military conflicts [1, 4]. This issue is socially significant because of the severe disability rate, which according to various authors, ranges from 30.2% to 51.0% [1, 3, 4].

Surgery for injuries to the thoracic and lumbar spine is aimed at activating patients as early as possible, which is achieved by stabilizing the injured segment with various types of instrumen-

tation [1]. Particularly, transpedicular fixation, which allows for extra-focal fusion through a posterior approach, has become most common [1–3]. Nevertheless, penetrating fractures often require resection of the injured vertebral body to decompress neural structures [2–4]. Additionally, spondylectomy may be required in cases of comminuted fractures (A3 and A4 types according to AO Spine) as well as for segmental release in rigid post-traumatic kyphosis [5, 6]. Thus, a wide defect of the anterior column is formed, which eliminates its support capability and requires replacement with an implant that performs a load-bearing function.

Routine use of anterior spinal fusion began in the 1950s [5]. In the beginning,

the resected section of the spinal column was filled with an autologous or allogeneic bone graft [7]. Subsequently, implants made of inorganic materials, which were more resistant to axial loads, were used for this purpose. A new milestone in anterior spine surgery was the titanium mesh cage (Harms–Korb), proposed by Harms in 1986 [8, 9]. This device is still used in spinal surgery and has been considered the gold standard for many years [6, 8, 9]. However, with extensive experience in its use, a number of disadvantages have been revealed, the key one being the low accuracy of selecting the cage length for the size of the bone defect [6, 8, 10]. Therefore, since the mid-1990s, devices have been developed for adjusting the size of the implant

directly in the resection area [5, 6, 8]. The next stage in the development of support interbody fusion technology was influenced by the era of minimally invasive surgery [2]. The placement of cages under conditions of limited visual and manual control, as well as the need to significantly increase the height of the device *in situ*, served as reasons for the introduction of a new type of implant in the late 2000s [5, 10]. The key difference between modern expandable devices is the vertical expansion mechanism, which enables direct reconstruction of the interbody space [7, 10, 11].

The large number of articles dedicated to this issue highlights its relevance and requires an analysis of the role and place of these devices in the structure of modern surgical treatment of spinal injury.

The objective is to perform a systematic analysis of contemporary scientific data characterizing the clinical effectiveness of expandable implants for vertebral body replacement in the complex surgical treatment of patients with thoracic and lumbar spine injuries.

Material and Methods

In accordance with the recommendations of the Cochrane Handbook for Systematic Reviews [12] and the recommendations on preferred reporting items for systematic reviews and meta-analyses (PRISMA) [13], we conducted a systematic review of the literature. The review protocol was not preregistered.

The literature search was performed in the databases (platforms) of the Cochrane Library, PubMed, and Medline from the time of publication of the first article until February 2025, without restrictions on the level of evidence or publication status. The search was carried out separately in each database using individually adapted search strategies. Additionally, we manually reviewed the reference lists of included studies to identify potentially relevant articles. We did not contact the authors of the articles to obtain additional data.

The search was performed using the following terms and keywords: traumat-

ic vertebral fracture, corpectomy, spinal reconstruction, spinal fusion, and expandable implant.

The systematic review includes studies that meet the following criteria:

- retrospective randomized clinical studies;
- patients over the age of 18;
- single-level traumatic burst fractures of the thoracolumbar spine from T10 to L2, which were surgically treated with decompression of the spinal canal and neural structures using corpectomy, followed by corporodesis using expandable spinal cages with various transformation mechanisms;
- minimum follow-up period of 12 months;
- the presence of at least seven patients in each group (with/without fusion);
- availability of clinical and radiological data before and after surgery.

Exclusion criteria are based on studies not corresponding to the objectives of the analysis and subject to removal during screening: experimental studies, multilevel fractures, degenerative diseases, and cancer.

Two independent reviewers conducted the initial selection based on titles and abstracts, followed by a review of the full-text versions of the studies. Disagreements at the stages of reviewing the title, abstract, or full text of the article were resolved through discussion between the reviewers and the senior author. Duplicates were removed using the automatic function in Zotero, followed by manual review.

The data were collected by two independent researchers. The following results were obtained: general information about the article; number of patients; type of expandable spinal cage used for corporodesis; and data on quality-of-life indicators before and after surgery.

The search revealed 697 articles in databases and additional 23 through manual searching. After removing duplicates, 718 articles remained for initial screening. After evaluating titles and abstracts, 604 articles were excluded. The full texts of 114 articles were examined for details, and 95 of them were excluded

for the following reasons: retrospective non-randomized studies ($n = 41$), studies conducted on cadaver material ($n = 4$), articles on degenerative diseases ($n = 21$), insufficient data on quality-of-life indicators ($n = 17$), and reviews with a follow-up period of less than 12 months ($n = 12$). Therefore, 19 studies were included in the final analysis. A visual representation of the article selection process is given in Fig.

Given the heterogeneous nature of the included studies, which differed significantly by design (retrospective cohort studies, case series), surgical techniques used (types of approaches, combinations with fixation), implant types, and outcomes evaluated, it was considered inappropriate to perform a quantitative synthesis of data (meta-analysis).

Despite the fact that quantitative synthesis (meta-analysis) was impossible because of significant methodological and clinical heterogeneity of the included studies, a qualitative evaluation of the risk of systematic error was performed. For this purpose, the ROBINS-I (Risk Of Bias In Non-randomized Studies – of Interventions) tool was used in an adapted form, since all included studies were non-randomized (retrospective cohorts, case series). The assessment was conducted across seven key domains: bias associated with participant selection, surgery classification, deviations from the planned surgery, lack of data, outcome measurement, and choice of reported outcome. Most studies showed a moderate or high risk of systematic error, mainly in the domains of participant selection (lack of randomization and control groups) and outcome measurement (lack of assessors blinding, use of non-validated criteria for evaluating radiological findings). Studies that used standardized functional outcome assessment protocols (e.g., quality of life questionnaires) and radiological measurements performed by independent experts were evaluated as having a low risk of bias in the relevant domains. Nevertheless, because of the prevalence of retrospective designs and the absence of comparison groups, the overall risk of systematic error across all included studies can

be described as moderate to high, which restricts the strength of the review's conclusions and requires caution in interpreting the results.

Results and Discussion

The evolution of anterior spinal fusion techniques and devices for its implementation is closely linked to the historical stages of the development of spinal surgery. This process resulted in the creation of static implants that initially provided reliable fixation. Nevertheless, routine use of combined (posterior/anterior) stabilization has revealed a significant disadvantage of this type of endoprosthesis, given the complexity of precisely adapting it to the size of the defect being replaced. The placement of such a cage between the vertebrae under conditions of rigid dorsal instrumentation often resulted in injury to the endplates and, as a consequence, unstable fixation [6, 7, 10, 16, 18]. This circumstance predetermined the development of devices with height adjustment capabilities directly in the implantation area. The first expandable cages for support spinal fusion appeared in the mid-1990s and within a few years firmly integrated into standard surgical practice [5, 6, 11]. These devices were placed through conventional (open) approaches to the anterior parts of the spinal column, after which they were locked between the vertebrae by gradually opening them using various types of mechanisms (screw, worm-gear).

Consequently, the key advantage of the first expandable implants over static ones was their ability to be tightly placed between adjacent vertebrae, along with minimal risk of bone injury [6, 11, 18]. Spinal cages of this type marked a fundamentally new direction in the technology of support spinal fusion, which later became the foundation for the concept of direct reconstruction of the anterior support column [6, 8, 18, 19]. The worldwide trend toward minimally invasive surgeries, which emerged in spinal surgery in the mid-2000s, played a major role in transforming surgical ideology and implant design [20–24]. The

active implementation of thoracoscopic approaches and mini-lumbar surgeries has significantly reduced the scope of direct visual control and manual options available to surgeons, which in turn has placed new demands on spinal fusion devices. In particular, the need to deliver the spinal cage through a narrow working channel contributed to the development of handles that allow the implant to be rigidly fixed, placed in the resection area, and transfer the force applied by a surgeon to the expansion mechanism [6, 20, 23, 24]. The highest achievement in support spinal fusion technology is the concept of direct intervertebral height restoration, realized through the introduction of vertical expansion devices [6, 15, 22]. During controlled expansion, implants of this type create sufficient force to correct the sagittal profile while also have the ability of significant increase in their height (relative

to the folded state), which greatly facilitates their placement in the resection area [6, 11, 18, 24]. The mentioned above conceptual and technical solutions have had a major impact on surgical treatment strategies for both acute spinal injuries and fixed post-traumatic deformities [6, 14, 18]. The question of creating conditions for bone-metal blocks still remains open because of the complexity of filling the implant with autogenous bone, but the introduction of plastic osteoinductive materials has partially solved this issue.

Types of expandable spinal cages and their mechanical features

During the last two decades, a large number of expandable implants with different design features have been proposed. Analysis of recent articles has shown that the fundamental difference between modern implants is the vertical expansion (lift) mechanism, which

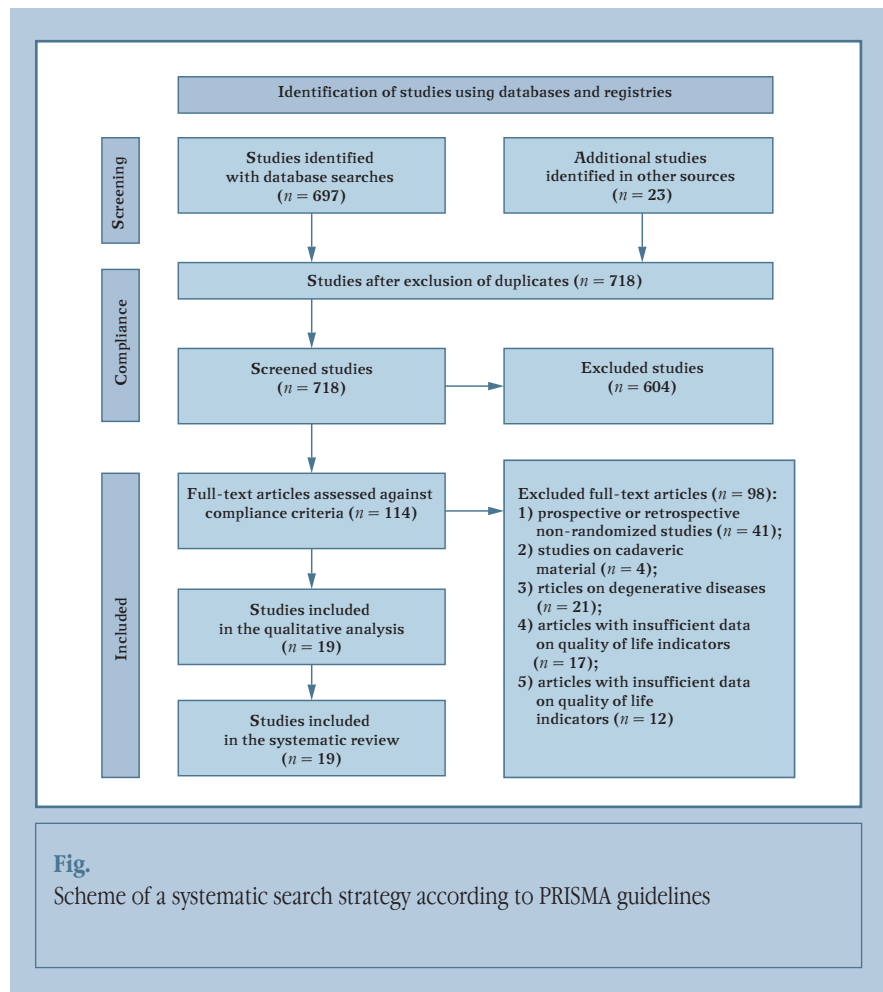


Fig.

Scheme of a systematic search strategy according to PRISMA guidelines

ensures direct reconstruction of the interbody space. Depending on the type of external force transmission to the cage expansion module, devices are currently classified as mechanical or hydraulic (Table 1). According to the literature, mechanical constructs most frequently use a screw-type expansion system, which is represented by rotating cylinders driven by a specialized instrument via a gear mechanism [18, 24]. Besides screw implants, ratchet-type implants that open up through distraction can also be included in the group of mechanical spinal cages [5, 11]. There are fewer articles about hydraulic implants, however, there are licensed implants of this type [14, 25] and data on their successful use, we decided to look at them as an alternative group.

Considering that the surgical treatment outcomes can be largely influenced by the technical characteristics of the spinal cage, we reviewed the literature analyzing the design features of mechanical and hydraulic implants in terms of their clinical and radiological efficacy.

Mechanical implants for support spinal fusion are high-tech orthopedic devices that can change their length by twisting or expanding. The structure consists of two hollow perforated cylinders made of biocompatible materials.

If it is a screw expansion, these parts are connected with a threaded joint. The collapsed spinal cage is rigidly fixed to the mounting handle and implanted between the vertebrae. Subsequently, rotation of the handle's internal part drives the gear mechanism, which transmits motion to the rotational module of the outer cylinder. This outer cylinder, in turn, has a threaded connection with the inner cylinder. Owing to the continuous thread cut along the entire inner cylinder, smooth unscrewing is ensured, thereby achieving linear expansion of the implant [10, 33]. The screw-expansion-based devices became most common and are manufactured by leading medical companies. The main advantage of these systems is their smooth expansion, which largely depends on the thread characteristics (profile, pitch) specified by the manufacturer. The combined

action of the gear transmission and vertical expansion creates a uniform distraction force adequate for segmental correction of the sagittal profile [11, 18]. Nevertheless, according to a number of authors [7, 10], excessive mechanical impact and structural rigidity create local areas of increased stress at the points of contact between the implant surfaces and the vertebral endplates. Therefore, it is recommended to achieve maximum congruence by adjusting the angles of the contact surfaces to the natural curves of the spine [11, 19]. Special precautions are necessary when using this type of spinal cages in patients with reduced bone mineral density, when the risk of endplate prolapse increases significantly [14, 18, 19]. Some studies point out that the combination of expandable screw-type implants with larger footplate surface can significantly improve the clinical and radiological outcomes of surgical treatment for patients with osteoporosis [8, 11, 14, 19].

In mechanical distraction-type cages, the inner and outer elements (cylinders) are connected by an analogue of a ratchet mechanism [5, 18]. The implant insertion tool consists of an expander with two branches, one of which is attached to the supporting (lower) cylinder, while the other secures the distal end of the mobile part of the implant (upper cylinder). After the implant is correctly placed between the vertebrae, the spinal cage elements are distracted, causing the ratcheted steps on the walls of the upper cylinder to interlock with the locking ring of the lower cylinder. The smoothness of expansion of such an implant is defined by the height of the steps of the self-locking module [6, 9, 18]. For example, in the most well-known device of this type, SynEx, locking occurs every 2.5 mm [18]. Hence, despite the simplicity and reliability of the ratchet mechanism, these systems cannot provide smooth vertical expansion, and consequently, the risk of hyperextension of the operated spinal segment significantly increases. According to literature sources [7, 10, 14, 18], adverse effects of excessive mechanical impact on the vertebral endplates most often occur when using distraction-

type implants. In all likelihood, clearer indications need to be formulated for the use of these devices, especially in individuals with low bone mineral density.

Systems with a hydraulic expansion mechanism are a rather new development in support spinal fusion technology, but the available literature provides some insights into their biomechanical characteristics and clinical response. The design of these devices (in particular, Hydrolift, Aesculap AG) features a casing made of bioinert materials with an integrated hydraulic system consisting of an expandable polymer chamber, a fluid reservoir, and a valve mechanism. The mobile (extendable) part of the implant is a cylindrical assembly integrated into the main body above the polymer chamber. The ends of the cage are equipped with footplates with adjustable angles of inclination. The implantation tool is a tube on which the device is secured and delivered to the intervertebral space. This equipment is used for all subsequent procedures. In particular, after placing the implant, a hydraulic applicator is introduced through the tube. And this applicator is used to infuse sterile saline solution under pressure (up to 30 bar). By controlling the pressure and expanding the polymer chamber, the mobile part of the spinal cage is smoothly released, ensuring controlled expansion and high-precision correction. After implementing the main goals of the surgery, the axial clamp of the implant is fastened (to block backflow of the saline solution), and the hydraulic applicator with the positioning tube is gradually removed. The footplates also have a unique design feature: they are self-adjusting to the angles of physiological curves of the spine by means of free axial play (within 10°) as they come into contact with the vertebral endplates. After segmental correction is achieved, the footplates are secured with locking screws. According to the specifications for installation recommended by the device manufacturers and a number of authors, it is necessary to perform a gentle resection of the vertebra (strictly according to the size of the implant), which is often problematic in cases of burst fractures (A3, A4). One

Table 1

Biomechanical features of mechanisms of expandable spinal cages

Features	Hydraulic design of a device	Mechanical design of a device	
		Screw-based system	Ratchet system
Material	Titanium (Ti6Al4V)	Titanium (Ti6Al4V); PEEK	Titanium (Ti6Al4V)
Expansion mechanism	Hydraulic (0.9% sterile NaCl solution)	Screw expansion mechanism (<i>in situ</i>)	Self-locking ratchet mechanism
Expansion accuracy	Continuous adjustment	Continuous height adjustment	Discrete expansion (fixed pitch of 2.5 mm)
Locking mechanism	Axial locking (12 Nm)	Locking screw	Expansion ring

of the main criteria for evaluating the efficiency of support spinal fusion is the integrity of the vertebral endplates, which, if injured, can cause implant subsidence and unstable fixation. According to literature sources [14, 25], when using hydraulic spinal cages, the risk of injury to the endplates is significantly lower compared to mechanical cages, especially in patients with osteoporosis, which the authors associate with smoother distraction and physiological self-adjusting of the footplates. Among the relative disadvantages are a higher percentage of correction loss compared to mechanical systems (unsealed chamber, unstable fixation of footplates), closed contour and low osseointegration, and a high cost. The advisability of using implants with a hydraulic expansion in cases of subacute and chronic injuries is also questionable, since a pressure of 30 bar may not be sufficient to correct the sagittal profile with the recommended conservative resection volume [14, 17].

Therefore, it may be said that each of the modern types of devices for support spinal fusion is characterized by specific biomechanics, the features of which must be considered when planning surgeries.

Analysis of the clinical and radiological efficacy of expandable spinal cages

The articles included in the analysis on the use of expandable implants for support spinal fusion in the surgical treatment of patients with injuries to the thoracic and lumbar spine are given in Table 2.

According to the literature, modern expandable spinal cages are characterized by a wide range of applications in spinal injuries. The authors report favorable outcomes of surgeries using various combinations of screw spinal fusion and interbody implants. Most articles discuss the combination of transpedicular fixation and anterior support fusion in a posterior/anterior (P/A) sequence. Objective data on the positive effect of expandable implants on the outcomes of P/A procedures are presented in a number of studies [17, 18, 20, 21, 28]. Grobost et al. [28] highlight the need for early reconstruction of the anterior support column, which, along with the use of expandable implants, allows for the stable rehabilitation of patients with thoracic and lumbar spine injuries. Meanwhile, Pesenti et al. [20] report a mean loss of reduction achieved after 12 months within 1° and the formation of a complete bone-metal block in 100% of cases that is consistent with the data of Lang et al. [17], according to which the values of these indicators are $2.4^\circ \pm 4.0^\circ$ and 97.9%, respectively. A number of specialists also emphasize the key role of modern spinal cages in staged (anterior/posterior/anterior – A/P/A) surgical treatment of fixed post-traumatic kyphosis [22].

Due to the development of vertical expansion mechanisms in interbody implants, there has been a trend toward modifying surgical techniques, in particular, changing the sequence of surgical steps. If previously, support spinal fusion was usually the final step in surgery, now it is preferred to perform it together with

reduction of segmental kyphosis. This anterior/posterior (A/P) approach is only suitable for AO Spine type A fractures, given the absence of translational risk. In contrast, for three-column type B and C injuries, initial posterior stabilization (a P/A approach) is mandatory to prevent intraoperative vertebral displacement. In this regard, studies have been performed to examine the efficacy of support spinal fusion in the structure of A/P surgeries. For example, Cappelletto et al. [26] reported clinical and radiological outcomes in 13 patients after anterior reconstruction and transpedicular fixation, comparable to the results of the conventional P/A technique.

There are fewer articles analyzing the functionality of expandable devices in isolated anterior procedures. Nonetheless, the studies included in the review suggest that direct (interbody) reduction of kyphosis is a viable treatment for acute thoracolumbar injuries, as is anterior fixation (spinal cage + screw anterior instrumentation), which allows for minimal loss of correction within the mean statistical range. [6, 27].

Studies on the use of expandable implants in extracavitary removal of thoracic and lumbar vertebrae are also of particular interest. The technical features of performing support spinal fusion through a posterolateral approach include a narrow passageway limited by neural structures, as well as the location of the resection area away from the direct angle of the surgical approach. It is often challenging to place a spinal cage of an adequate size in such conditions,

Table 2

Outcomes of clinical studies on the use of expandable spinal cages

Study	Number of cases	Follow-up period	Conclusion
Graillon et al. [6]	93	12 months	Anterior approach using an expandable spinal cage is a relatively safe and effective technique that provides long-term restoration of vertebral height and correction of kyphotic deformity in thoracic fractures without damaging the posterior wall.
Pesenti et al. [20]	39	12 months	The combination of percutaneous fixation with anterior fusion using an expandable spinal cage provides stable deformity correction, low complication rate and rapid pain attenuation.
De la Cruz-Álvarez et al. [16]	8	21 months	Corpectomy through posterior approach with the installation of an expandable implant and transpedicular fixation is an effective technique for the treatment of thoracolumbar fractures, providing decompression, stabilization and correction of spinal deformity, while minimizing the risks associated with anterior or combined approaches, reducing the duration of surgery and decreasing intraoperative blood loss.
Pham et al. [15]	7	28.8 months	Corpectomy through a posterior approach with transpedicular fixation and installation of expandable implants is an effective alternative to combined approaches, providing to avoid the risks associated with anterior approach.
Richardson et al. [27]	42	12.9 months	Anterior corpectomy with reconstruction using an expandable titanium spinal cage is a relatively safe alternative to posterior fixation, providing complete decompression of the spinal cord and stable restoration of the anterior column.
Lee et al. [11]	42	39.5 months	Expandable spinal cages provide better correction of the kyphosis angle and a lower rate of complications such as implant subsidence compared to static implants.
Grobost et al. [28]	44	12 months	Early corpectomy (within 72 hours after injury) is associated with better functional outcomes and lower complication rate compared with delayed intervention, especially in patients with high risk of nonunion (McCormack score ≥ 7)
Lindtner et al. [18]	37	38 months	Monosegmental reconstruction of the anterior column with an expandable spinal cage is acceptable for incomplete burst fractures or fractures with a single endplate split line, preserving the motion segment in young patients, whereas bisegmental reconstruction is recommended for multiple fracture lines or significant endplate damage.
Smits et al. [21]	105	49 months	Thoracoscopic approach using an expandable implant is a safe and effective technique or the treatment of unstable fractures, providing stable reconstruction of the anterior spinal column, a low complication rate and satisfactory long-term functional outcomes.
Smits et al. [22]	14	26 months	Thoracoscopic approach using an expandable cage provides stable correction of kyphosis, high fusion rates and good functional outcomes with minimal surgical trauma.
Cappelletto et al. [26]	39	12 months	Expandable implants provide stable reconstruction, correction of deformity and restoration of vertebral height with a low risk of complications.
Lang et al. [17]	96	24 months	Application of an expandable implant provides reliable stabilization, a high fusion rate and clinically insignificant loss of correction, while functional outcomes remain satisfactory even in the long term, despite incomplete restoration of quality of life to normal.
Kreinst et al. [14]	47	36 months	Hydraulic expandable spinal cage provides long-term stability, maintains spinal correction and demonstrates clinical results comparable to the use of bone autograft.

End of the Table 2

Outcomes of clinical studies on the use of expandable spinal cages

Study	Number of cases	Follow-up period	Conclusion
Kreiness et al. [25]	7	39 months	Combined posteroanterior stabilization using a hydraulic implant allows for stable repositioning and long-term satisfactory clinical outcomes in patients with multisegmental fractures, although it does not fully restore the previous quality of life
Segi et al. [19]	46	24 months	A minimally invasive lateral approach using a cage with rectangular footplate demonstrates advantage over the conventional technique using cylindrical cage in the treatment of osteoporotic vertebral fractures, providing less intraoperative blood loss, shorter surgery duration, reduced risk of implant subsidence, and better deformity correction with a high rate of bone fusion.
Urbanski et al. [23]	28	12 months	A minimally invasive posterolateral transpedicular approach for thoracolumbar corpectomy demonstrates high efficacy in kyphosis correction in posttraumatic vertebral fractures. Study results demonstrated significant improvements in spinal stability and neurological status in patients with kyphosis correction on mean by 14.3° and a low rate of serious complications (7%).
Felton et al. [24]	123	No data	Application of spinal cage assembly technique in situ in the corpectomy space allows for separate transport of large implant components, simplifying their installation in limited surgical access. A key advantage of this approach is the possibility to increase the footplate diameter, significantly increasing the support area on adjacent vertebral bodies. This reduces the risk of implant subsidence and ensures more stable fixation.
Deml et al. [29]	48	21 months	A modular expandable PEEK implant for vertebral body replacement has proven its efficacy and safety for anterior column reconstruction after corpectomy, providing stable kyphosis correction with minimal loss of correction (1.6°) and a high fusion rate (92.1%). Its biomechanical advantages and radiotransparency make it a promising alternative to titanium implants.
Ortiz Torres et al. [30]	96	14 months	Anterolateral corpectomy for thoracolumbar burst fractures provides satisfactory correction of kyphosis (mean correction is 7.7°), but there is a loss of correction in 36.5% of cases associated with the use of bone autografts, their displacement and subsidence, whereas expandable titanium cages demonstrate better stability

which may be associated with complications related to cage subsidence. Therefore, most specialists recommend using implants with a vertical expansion function for posterior procedures. Thus, Lee et al. [11] show objective data demonstrating the better corrective and stabilizing capabilities of expandable spinal cages compared to static ones. According to De la Cruz-Álvarez et al. [16], posterior surgeries using transformable implants allow for adequate reduction of segmen-

tal kyphosis and reliable stabilization of the thoracic and lumbar spine (correction loss within 1°). It is also noteworthy that posterolateral lumbar spinal fusion is unique in that it requires the placement of large implants and prevents the use of aggressive techniques (excessive traction, resection) on the spinal nerve roots. This circumstance necessitates the use of devices with the ability to multiply the longitudinal size and modular assembly in the resection cavity. For

example, Felton et al. [24] offered a way to set up and place big spinal cage parts (footplates, central module) right in the interbody space, which showed its clinical effectiveness and safety.

Consequently, analysis of literature revealed that surgery using expandable spinal cages provided satisfactory clinical and radiological outcomes regardless of the method of placement. This circumstance is probably associated with both the positive qualities of modern implants

Table 3

Radiological outcomes of the application of expandable spinal cages with different expansion mechanisms

Expansion mechanism of the vertebral body replacement implant	Study	Subsidence, mm	Loss of correction, degrees
Hydraulic (0.9% sterile NaCl solution)	Kreinst et al. [14]	1.8 ± 1.9*	3.4 ± 3.1 during 36 months
	Kreinst et al. [25]	No data	3.5 ± 2,0 during 39 months
Screw expansion mechanism (<i>in situ</i>)	Lang et al. [17]	2.4 ± 1.1	2.4 ± 4.0
	Lindtner et al. [18]	No data	2.8 (median) during 38 months
	Deml et al. [29]	1.5 ± 0.7	1.6 ± 0.9
	Cappelletto et al. [26]	No data	2.1**
	Pesenti et al. [20]	No data	~1.0**
Self-locking ratchet mechanism	Lee et al. [11]	3.5 ± 1,8	4.2 ± 2.1 (in the expandable group)
	Graillon et al. [6]	7% (frequency >4 mm)	3.6**
	Urbanski et al. [23]	3.6 ± 1.7	2.1 ± 1.4
		No data	7.7**

* The authors report the value of 1.8 ± 1.9 mm as the “mean segmental disc height,” which indirectly reflects subsidence; ** the original article reports only the mean value without standard deviation.

and the minimally invasive character of the procedures, which has recently been widely supported by most specialists.

For a visual comparison of the radiological outcomes of using spinal cages with different expansion mechanisms, a summary table (Table 3) has been compiled, which presents data on implant subsidence and loss of kyphosis angle correction in the postoperative period. The analysis indicates that all device types provide stable reconstruction with a reasonable level of correction loss, but there are some differences depending on the expansion mechanisms.

According to Table 3, the lowest rates of subsidence and loss of correction are recorded when using implants with hydraulic and screw expansion mechanisms. Ratchet-type implants demonstrate a higher, but still clinically acceptable, degree of subsidence and loss of correction. The data obtained are in line with the previously described biomechanical characteristics of each type of implant and confirm their overall efficacy in surgical practice.

It should also be pointed out that the above articles do not provide a direct comparative analysis of immediate and long-term clinical outcomes depending on the type of expandable device. Despite a detailed search, no research

articles with similar objectives could be found, and therefore conclusions about the superior efficacy of spinal cages with different expansion mechanisms can only be drawn indirectly. However, the data from these descriptive studies suggest that the clinical and radiological outcomes are identical when using both mechanical devices and hydraulic implants [14, 17, 26, 28].

The issue of support spinal fusion in patients with low bone mineral density is discussed separately. The authors share the view that expandable implants are preferable to static ones in cases of concomitant osteoporosis because of the smooth and balanced (maintaining the angles of the endplates) wedging of the device between the vertebrae [7, 10, 19, 29]. According to some experts [14, 25], hydraulic implants best meet these criteria. Furthermore, a number of researchers [8, 19, 24] believe that the risk of cage prolapse in patients with concomitant osteoporosis can be significantly reduced by using large-area footplates.

Conclusion

A systematic review has shown that expandable body replacement implants occupy an important place in modern spinal surgery, significantly broadening the technical possibilities for both open

and minimally invasive procedures in patients with spinal injuries.

The analysis of the literature showed that modern expandable implants are universal in their application: they are effective in isolated anterior procedures, in combination with transpedicular fixation using the P/A and A/P techniques, as well as in complex multi-level reconstructions. Their role in minimally invasive surgery is of particular note, where the possibility to significantly increase the height of the implant *in situ* and the modular delivery system allow adequate spinal fusion to be performed through limited approaches.

Therefore, expandable body replacement implants have become not just a technical improvement but also a tool for implementing a personalized surgical approach to spinal injuries, adapting the procedure to the specific anatomical features and characteristics of each patient's pathology.

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The study was approved by the local ethics committee of the institution.

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Address correspondence to:

Shuvalov Stanislav Dmitrievich
V.I. Razumovsky Saratov State Medical University,
148 Chernyshevskogo str., Saratov, 410002, Russia,
i@shuvalovstan.ru

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Stanislav Dmitrievich Shuvalov, MD, neurosurgeon, junior researcher, Department of Innovative Projects for Neurosurgery and Vertebrology, Scientific Research Institute of Traumatology, Orthopedics and Neurosurgery, V.I. Razumovsky Saratov State Medical University, 148 Chernyshevskogo str., Saratov, 410002, Russia, eLibrary SPIN: 7454-5759, ORCID: 0000-0002-8095-9398, shuvalov.stan@yandex.ru;

Aleksey Evgenyevich Shulga, MD, PhD, neurosurgeon, senior researcher, Department of Innovative Projects for Neurosurgery and Vertebrology, Scientific Research Institute of Traumatology, Orthopedics and Neurosurgery, V.I. Razumovsky Saratov State Medical University, 148 Chernyshevskogo str., Saratov, 410002, Russia, eLibrary SPIN: 4018-3890, ORCID: 0000-0001-8476-0231, doc.shulga@yandex.ru;

Sergey Petrovich Bazhanov, DMSc, neurosurgeon, Head of the Department of Innovative Projects for Neurosurgery and Vertebrology, Scientific Research Institute of Traumatology, Orthopedics and Neurosurgery, V.I. Razumovsky Saratov State Medical University, 148 Chernyshevskogo str., Saratov, 410002, Russia, eLibrary SPIN: 2621-4519, ORCID: 0000-0001-9474-9095, baj.s@mail.ru;

Vladimir Vladimirovich Ostrovskij, DMSc, neurosurgeon, director of the Scientific Research Institute of Traumatology, Orthopedics and Neurosurgery, V.I. Razumovsky Saratov State Medical University, 148 Chernyshevskogo str., Saratov, 410002, Russia, eLibrary SPIN: 7078-8019, ORCID: 0000-0002-8602-2715, sarniito@yandex.ru;

Vladimir Sergeevich Tolkachev, MD, neurosurgeon, junior researcher, Department of Innovative Projects for Neurosurgery and Vertebrology, Scientific Research Institute of Traumatology, Orthopedics and Neurosurgery, V.I. Razumovsky Saratov State Medical University, 148 Chernyshevskogo str., Saratov, 410002, Russia, eLibrary SPIN: 9093-0492, ORCID: 0000-0001-6580-4403, vladimir.tolkachev@yandex.ru.

