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Subsidence of Vertebral Body Replacement Prostheses in Spinal Tumors: A Systematic Review

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Abstract
Background. Vertebral body replacement is one of the key surgical methods for the treatment of spinal tumors. One of its most common complications is vertebral body implant subsidence.
The aim of the review — to compare the subsidence rates of various types of vertebral body implants used in the surgical treatment of thoracic and lumbar spinal tumors in order to determine the optimal reconstruction methods for patients with spinal tumors.
Methods. A systematic literature review was conducted in accordance with the PRISMA guidelines. The search was performed in the PubMed, Google Scholar, and eLIBRARY databases. Studies were included if they involved vertebral body replacement in patients aged 18 years and older with oncologic lesions, provided a clear definition of subsidence, and analyzed risk factors. Various implant types were evaluated, including expandable, mesh, 3D-printed commercial, and patient-specific prostheses.
Results. Thirteen studies were included in the analysis (12 retrospective and 1 prospective) comprising a total of 661 patients. The highest subsidence rates were observed with titanium mesh cages, ranging from 63.8 to 71.4%. Expandable implants demonstrated more favorable outcomes, with subsidence rates from 5.3 to 35.3%. The results for 3D-printed implants were the most inconsistent, ranging from 0 to 100% across studies. The follow-up period varied from 7.4 to 101 months.
Conclusions. Expandable implants demonstrate the most favorable subsidence rates in vertebral body replacement for patients with spinal tumors. The high subsidence rates of titanium mesh cages may be attributed to a mismatch between the elastic modulus of the implant and bone tissue. 3D-printed implants require further investigation to optimize their design and clinical use. An individualized approach to prosthesis selection considering risk factors is essential.

Keywords: vertebral body replacement; spinal tumors; implant subsidence; expandable implants; titanium mesh cages; 3D-printed implants; spondylectomy.

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Проседание протезов тел позвонков при опухолях позвоночника: систематический обзор литературы

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Реферат

Актуальность. Протезирование тел позвонков является одним из ключевых методов хирургического лечения опухолевых поражений позвоночника. Одним из наиболее распространенных его осложнений является проседание протеза тела позвонка.

Цель обзора — сравнить частоту проседания различных типов протезов тел позвонков при хирургическом лечении опухолевых поражений грудного и поясничного отделов позвоночника для определения оптимальных методов реконструкции позвоночного столба у пациентов с опухолями позвоночника.

Материал и методы. Проведен систематический обзор литературы в соответствии с рекомендациями PRISMA. Поиск осуществлялся в базах данных PubMed, Google Scholar и eLIBRARY. Были включены исследования, посвященные протезированию тел позвонков при опухолевых поражениях у пациентов 18 лет и старше, с четким определением проседания и анализом факторов риска. Анализировались различные типы имплантатов: раздвижные, сетчатые, серийные и индивидуальные 3D-протезы.

Результаты. В анализ включено 13 исследований (12 ретроспективных, 1 проспективное) с участием 661 пациента. Наибольшая частота проседания зафиксирована для титановых сетчатых протезов — от 63,8 до 71,4%. Раздвижные имплантаты продемонстрировали более благоприятные результаты с частотой проседания от 5,3 до 35,3%. Результаты применения 3D-имплантатов оказались наиболее противоречивыми, варьируя от 0 до 100% в различных исследованиях. Период наблюдения составлял от 7,4 до 101 мес.

Заключение. Раздвижные имплантаты демонстрируют наиболее благоприятные результаты в отношении частоты проседания при протезировании тел позвонков у пациентов с опухолями позвоночника. Высокая частота проседания титановых сетчатых протезов может быть обусловлена несоответствием модуля упругости имплантата и костной ткани. 3D-протезы требуют дальнейшего изучения для оптимизации их дизайна и клинического применения. Необходим индивидуальный подход к выбору типа протеза с учетом факторов риска.

Ключевые слова: протезирование тел позвонков; опухоли позвоночника; проседание имплантатов; раздвижные протезы; титановые сетчатые протезы; 3D-имплантаты; спондилэктомия.

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INTRODUCTION

Vertebral body replacement is one of the key surgical methods for the treatment of spinal tumors. This procedure restores the load-bearing function and stability of the spinal column after the resection of the affected vertebra [1, 2]. The long-term effectiveness of the method largely depends on the stability of the implanted device and its integration with the adjacent bone structures [3]. Vertebral body implant subsidence is one of the most common complications, which can lead to sagittal imbalance, compression of neural structures, pain syndrome, and, ultimately, the need for revision surgery [4].

Assessing the incidence of implant subsidence and identifying the factors influencing its development is critically important for optimizing surgical strategies and improving long-term treatment outcomes [5]. Modern spinal surgery utilizes a wide range of vertebral body implants, including traditional titanium mesh cages, expandable implants, and innovative 3D-printed and patient-specific prostheses [6]. Each implant type has unique biomechanical properties that may differentially affect the risk of subsidence.

Despite significant advances in the development of new implant types, the literature lacks systematized data on the comparative effectiveness of different vertebral body prostheses in terms of subsidence rates in spinal tumor cases.

The aim of the review — to compare the subsidence rates of various types of vertebral body implants used in the surgical treatment of thoracic and lumbar spinal tumors in order to determine the optimal reconstruction methods for patients with spinal tumors.

METHODS

This study is a systematic literature review conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A literature search was performed in the PubMed, Google Scholar, and eLIBRARY electronic databases in both Russian and English using the following keywords: vertebral body replacement, vertebral body prosthesis, vertebral body reconstruction, spinal tumor, spine tumor, vertebral tumor, spinal metastases, implant subsidence, prosthesis subsidence, cage subsidence, spondylectomy, corpectomy, vertebrectomy, titanium mesh, expandable cage, 3D printed implant, spinal reconstruction, anterior spinal fusion. The initial search identified 1054 potentially relevant articles (Figure 1).

The selection of studies was based on the PICO framework (Population, Intervention, Comparison, Outcome). The Population (P) included adult patients (18 years and older) with primary or metastatic tumors of the thoracic and/or lumbar spine. The Intervention (I) was vertebral body replacement using various types of implants (expandable, mesh, 3D-printed commercial, or pacient-specific). The Comparison (C) was made between different implant types. The primary Outcome (O) was the incidence of implant subsidence.

Inclusion criteria:

1) language of publication — English or Russian;

2) publication period — from 2010 to 2025 inclusive;

3) study design — randomized controlled trial, cohort study, case-control study, or case series with at least 10 patients;

4) full-text article available.

Exclusion criteria: review articles, editorials, letters to the editor, and poster presentation.

Studies were included if they focused on vertebral body replacement for spinal tumors, contained a clear definition and measurement methods of subsidence, and analyzed risk factors associated with subsidence. Studies dedicated exclusively to traumatic or infectious spinal conditions, as well as duplicate publications, were excluded.

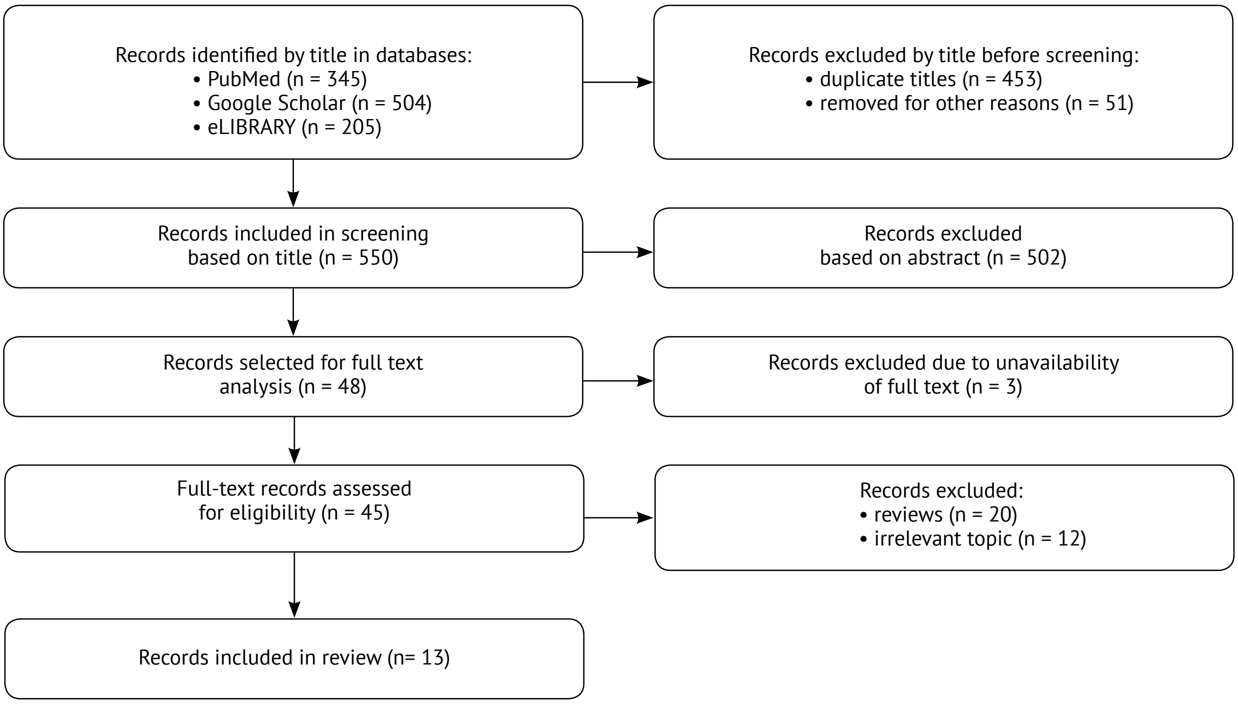

Figure 1. Flow diagram of article search and selection

Two independent reviewers performed the screening of titles and abstracts, followed by a full-text review of selected articles. Disagreements were resolved through discussion with a third reviewer when necessary. The following data were extracted from each included study: study design, patient characteristics (number, age, sex, tumor type and location), implant type, definition and measurement methods of subsidence, subsidence rate, risk factors, and follow-up duration.

Data analysis was performed using quantitative and descriptive methods. Particular attention was paid to comparing subsidence rates among different implant types and analyzing the risk factors associated with subsidence.

RESULTS

In the course of a systematic literature review, 13 studies on vertebral body replacement in case of spinal tumors were analyzed. The vast majority (12 out of 13) had a retrospective design, while only one was prospective. The predominance of retrospective studies limits the ability to establish causal relationships based on the obtained results (Table 1).

Information on tumor type was provided in 11 out of 13 studies. Across these studies, 258 patients had primary tumors and 267 had metastatic lesions. For 136 patients from two studies, the tumor type was not specified. The mixed nature of tumor involvement (both primary and metastatic) in the analyzed studies indicates heterogeneity of the patient population, which may affect the generalizability of the findings to specific tumor types.

Regarding the types of implants used, 3D-printed vertebral body prostheses were the most frequently reported — mentioned in 7 out of 13 studies. Titanium mesh cages were used in four studies, expandable implants in three, patient-specific prostheses in five, and carbon fiber–reinforced polyetheretherketone (CFR-PEEK) implants in two studies. The diversity of implant types reflects the evolving nature of spinal reconstruction technologies and complicates direct comparison of outcomes across studies.

Table 1

Characteristics of included studies

Study	Study design	Patient population	Implant type	Follow-up period
Viswanathan A. et al., 2012 [7]	Retrospective cohort study	95 patients (24% with primary tumors, 76% with metastatic lesions)	Expandable titanium prosthesis	Median 7.4 months (range 1-62 months)
Yoshioka K. et al., 2017 [8]	Retrospective cohort study	47 patients (15 with primary spinal tumors, 32 with metastatic lesions)	Titanium mesh cage	Mean 70.2 months (range 17-120 months)
Girolami M. et al., 2018 [9]	Prospective case series	13 patients (8 with primary bone tumors, 5 with solitary metastases)	Patient-specific 3D-printed titanium prosthesis	Mean 10 months (range 2-16 months)
Li Z. et al., 2020 [10]	Retrospective cohort study	30 patients (23 with primary spinal tumors, 7 with metastatic lesions)	Titanium mesh cage	Mean 41.8 months (range 13-120 months)
Tang X. et al., 2021 [11]	Retrospective cohort study	27 patients (predominantly with primary spinal tumors, 4 with metastatic lesions)	3D modular prosthesis	Mean 22 months (range 12-41 months)
Shen F.H. et al., 2022 [12]	Case series, retrospective multi-center review	13 patients (8 with primary tumors, 5 with metastatic lesions)	Patient-specific implant made of CFR PEEK	Mean 8 months (range 1-21 months)
Zhou H. et al., 2022 [13]	Retrospective cohort study, case series	23 patients (18 with primary spinal tumors, 5 with metastatic lesions)	3D-printed prostheses (patient-specific and commercial)	Median 37 months (range 24-58 months)
Cao Y. et al., 2023 [14]	Retrospective cohort study, comparative study	20 patients with metastases in the thoracolumbar region	Artificial 3D-printed prosthesis	Median 21.8 months (range 12-38 months)
Chen Z. et al., 2023 [15]	Retrospective comparative study	35 patients (26 with primary malignant tumors, 9 with metastatic lesions)	Commercial 3D-printed prosthesis, titanium mesh cage	Mean 24.6 months (range 12-60 months)
Shimizu T. et al., 2023 [16]	Retrospective cohort study	136 patients (tumor type not specified)	Titanium mesh cage	Mean 101 months (range 36-232 months)
Hu J. et al., 2023 [17]	Retrospective cohort study	51 patients (33 with primary tumors, 18 with metastatic lesions)	3D-printed prostheses (patient-specific and commercial)	Median 21 months (range 7-57 months)
Hu X. et al., 2023 [18]	Retrospective cohort study	145 patients (79 with primary spinal tumors, 66 with metastatic lesions)	Titanium mesh cage, expandable titanium prosthesis, patient-specific 3D-printed prosthesis	Mean 53.61 months (range 12-149 months)
Schwendner M. et al., 2023 [19]	Retrospective cohort study, case series	25 patients (8% with primary spinal tumors, 92% with metastatic lesions)	Expandable prosthesis made of carbon fiber-reinforced polyetheretherketone (CFR-PEEK)	Median 295 days (range 13-491 days)

The duration of follow-up also varied among the studies. Five out of 13 studies reported median follow-up periods ranging from 7.4 to 37 months (with conversion of days to months for the study by M. Schwendner et al.). Eight studies reported mean follow-up durations ranging from 8 to 101 months. This wide variation in follow-up duration may influence the assessment of long-term outcomes and complication rates across studies.

The rates of implant subsidence varied considerably depending on the type of vertebral body prosthesis used. For titanium mesh cages, the incidence of subsidence ranged from 63.8 to 71.4%, as reported by K. Yoshioka et al. and Z. Chen et al., respectively [8, 15]. In the same study by Z. Chen et al., the performance of a 3D-printed commercial prosthesis was also evaluated, showing a subsidence rate of 64.3% [15].

Expandable implants demonstrated variable rates of subsidence. In the study by A. Viswanathan et al., the rate for a titanium implant was 12.6%, while in the study by M. Schwendner et al., the rate reached 35.3% for a CFR-PEEK implant [7, 19].

The results of 3D-printed implants were heterogeneous. In the study by X. Hu et al., no cases of subsidence were reported among 51 patients who received 3D-printed prostheses (both patient-specific and commercial) [18]. Similarly, F.H. Shen et al. reported no subsidence with CFR-PEEK implants featuring custom titanium endplates [12]. However, in the study by M. Girolami et al., subsidence occurred in all patients (100%) who received patient-specific titanium 3D-printed prostheses [9]. In the study by H. Zhou et al., the subsidence rate of 3D implants was 21.7%, while X. Tang et al. reported a rate of 38.5% for modular 3D-printed prostheses [11, 13] (Table 2).

Table 2

Subsidence rates by implant type

Study	Implant type	Subsidence rate	Definition of subsidence	Time of detection
Viswanathan A. et al., 2012 [7]	Expandable titanium prosthesis	12/95 (12.6%)	Migration > 1 mm	Immediately after surgery and more than 30 days postoperatively
Yoshioka K. et al., 2017 [8]	Titanium mesh cage	30/47 (63.8%)	> 2 mm	One month after surgery
Girolami M. et al., 2018 [9]	Patient-specific 3D-printed titanium prosthesis	13/13 (100%)	4.3±5.7 mm	At the last follow-up
Li Z. et al., 2020 [10]	Titanium mesh cage	8/52 (15.4%)	10.9±4.5 mm	At the last follow-up
Tang X. et al., 2021 [11]	3D modular prosthesis	10/26 (38.5%)	Migration > 2 mm	During the follow-up period
Shen F.H. et al., 2022 [12]	Patient-specific implant made of CFR PEEK	0/13 (0%)	Not applicable	Not applicable
Zhou H. et al., 2022 [13]	Patient-specific 3D-printed prostheses	1/10 (10%)	Migration > 2 mm	At the last follow-up
	Commercial 3D-printed prostheses	4/13 (30.8%)	Migration > 2 mm	At the last follow-up
Cao Y. et al., 2023 [14]	3D-printed self-stabilizing artificial vertebra	7/10 (70%)	1.8±2.1 mm	At the last follow-up
	Titanium mesh cage	9/10 (90%)	5.2±5.1 mm	At the last follow-up

End of Table 2

Study	Implant type	Subsidence rate	Definition of subsidence	Time of detection
Chen Z. et al., 2023 [15]	Commercial 3D-printed prostheses	9/14 (64.3%)	Decrease in mean vertebral body height > 3 mm	At the last follow-up
	Titanium mesh cage	15/21 (71.4%)	Decrease in mean vertebral body height > 3 mm	At the last follow-up
Shimizu T. et al., 2023 [16]	Titanium mesh cage	44/136 (32.4%)	2-18 mm	One month after surgery
Hu J. et al., 2023 [17]	3D-printed prostheses (patient-specific and commercial)	0/51 (0%)	Not applicable	Not applicable
Hu X. et al., 2023 [18]	Titanium mesh cage	18/70 (25.7%)	Not defined	At the last follow-up
	Expandable titanium prosthesis	4/75 (5.3%)	Not defined	At the last follow-up
Schwendner M. et al., 2023 [19]	Expandable prosthesis made of CFR-PEEK	6/17 (35.3%)	3.8±3.1 (1-8) mm	At the last follow-up

The degree of subsidence varied across studies, ranging from implant migration of more than 1 mm to segmental height loss exceeding 3 mm. The timing of subsidence detection also differed — from the immediate postoperative period to the final follow-up. In most studies, subsidence was assessed either one month postoperatively or during subsequent follow-up visits.

Implant instability rates were reported in 12 of the 13 studies. Recorded instability rates ranged from 0 to 32.4%, reflecting substantial variability in implant performance among studies. Information on the timing of implant instability was available in only three studies: one reported a mean time of 37.41 months, another a median of 31 months, and the third provided specific values of 24 and 36 months. In nine studies, no information on the timing of instability was provided, and in one study, this parameter was not applicable due to the absence of instability cases. The lack of consistent reporting on the timing of implant instability limits the ability to draw conclusions about the long-term performance of different implant types.

DISCUSSION

The present systematic review provides the first comprehensive analysis of vertebral body prosthesis subsidence in spinal tumors, encompassing various implant types and their clinical outcomes. The data demonstrate considerable variability in the incidence of subsidence across different prosthesis types, which has important clinical implications for selecting the optimal method of spinal reconstruction in oncologic patients.

The highest subsidence rates were observed with titanium mesh cages — ranging from 15.4 to 90.0%. These findings are consistent with previous reports indicating a high incidence of subsidence in titanium implants, particularly in the presence of osteoporosis or weakened endplates [20]. The high subsidence rates associated with titanium mesh cages may be attributed to the mismatch in elastic modulus between the implant and bone tissue, as well as stress concentration over a relatively small contact area with the vertebral endplates. These results align with biomechanical studies demonstrating that the high stiffness of titanium creates unfa-vorable conditions for load distribution at the implant-bone interface, especially in patients with com-promised bone quality due to oncologic disease [21, 22].

Expandable prostheses demonstrated more favorable outcomes, with subsidence rates ranging from 5.3 to 35.3%. The advantage of expandable designs lies in their ability to restore vertebral height accurately and distribute loads evenly across the endplates. Furthermore, expandable implants allow intraoperative height adjustment, promoting optimal contact with the surrounding bone structures.

The outcomes of using 3D-printed implants proved to be the most inconsistent, with reported subsidence rates ranging from 0 to 100% across studies. This considerable variability may be attributed to differences in implant design, manufacturing materials, and patient-specific characteristics. Although patient-specific 3D-printed prostheses are theoretically expected to achieve superior anatomical conformity, clinical results do not always confirm this assumption.

Titanium alloy remains the standard material for fabricating patient-specific 3D implants. Despite its biocompatibility and mechanical strength, titanium possesses notable biomechanical disadvantages. Even porous titanium structures exhibit a substantial mismatch in elastic modulus compared to bone tissue — approximately 110 GPa for titanium versus 3.78-14.64 GPa for bone [22, 23]. This discrepancy leads to a stress-shielding effect, in which the stiffer implant bears the majority of the mechanical load, thereby reducing stimulation of the surrounding bone. According to Wolff's law, insufficient mechanical loading induces bone resorption and weakening, which ultimately promotes implant subsidence and structural instability [24]. Additionally, stress concentration over a relatively small contact area between a rigid titanium implant and compromised vertebral endplates further predisposes to subsidence. In oncologic settings, where bone quality is often impaired by tumor involvement, chemotherapy, or radiotherapy, these biomechanical factors become even more critical.

Paradoxically, while the patient-specific geometry of 3D-printed prostheses was intended to optimize load distribution, it does not address the fundamental mismatch in material mechanical properties. This may explain why even anatomically precise custom implants can show high subsidence rates, as reported by M. Girolami et al., where the incidence reached 100% [9]. This issue underscores the need for developing novel materials for 3D printing, such as PEEK-based composites, that could better approximate the mechanical characteristics of bone while retaining the advantages of patient-specific design.

Study limitations

This systematic review has several limitations. First, significant heterogeneity among the included studies in terms of design, patient populations, and implant types limits the feasibility of performing a quantitative meta-analysis. Second, differences in the definition of subsidence and measurement methods complicate direct comparison of outcomes. Third, the relatively short follow-up periods in some studies may not adequately reflect long-term results.

CONCLUSIONS

This systematic review highlights the need for an individualized approach to selecting vertebral body replacement implants in patients with spinal tumors, taking into account various risk factors. Expandable implants demonstrate the most favorable outcomes with respect to subsidence rates, whereas 3D-printed prostheses require further investigation to optimize their design and clinical application.

DISCLAIMERS

Author contribution

Zaborovskii N.S. — study concept and design, drafting and editing the manuscript.

Shailieva Sh.L. — study concept and design, drafting and editing the manuscript.

Masevnin S.V. — literature search and review, drafting and editing the manuscript.

Smekalenkov O.A. — literature search and review, statistical data processing, data analysis and interpretation.

Murakhovsky V.S. — literature search and review, statistical data processing, data analysis and interpretation.

Ptashnikov D.A. — scientific guidance, editing the manuscript.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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