VERTEBRAL BONE DENSITY IN HOUNSFIELD UNITS AS A PREDICTOR OF INTERBODY NON-UNION AND IMPLANT SUBSIDENCE IN LUMBAR CIRCUMFERENTIAL FUSION

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Objective. To determine the values of Hounsfield units (HU) of the lumbar vertebrae predicting unsatisfactory radiological results of circumferential interbody fusion at the lumbar level.

Material and Methods. The data of patients who underwent a single-level decompression and stabilization intervention at the L4–L5 or L5–S1 level for degenerative diseases of the spine were analyzed. The CT images of the lumbar spine were assessed before surgery with the measurement of HU values of the vertebral bodies at the intervention level, as well as CT images one year after surgery to evaluate the degree of interbody block formation and subsidence of the cage. Three groups of patients were distinguished: patients with a formed interbody bone block and without cage subsidence (control group), patients with failed fusion and patients with cage subsidence.

Results. The study presents CT data of 257 patients. The incidence of non-union was 32.3 % (83/257), and of cage subsidence – 43.6 % (112/257). The proportion of patients with reduced bone mineral density (BMD) was 26.1 % (67/257). Patients with non-union and subsidence had higher ODI scores ($p = 0.045$ and $p = 0.050$, respectively) compared to controls. The presence of fusion failure and subsidence is associated with reduced BMD ($p < 0.05$), HU values of vertebrae ($p < 0.05$), and higher ODI score ($p < 0.05$). According to the ROC analysis, threshold HU values were determined equal to 127 HU, 136 HU and 142 HU for the L4, L5, S1 vertebral bodies, respectively. Upon reaching these values, the risk of a combination of fusion failure and subsidence increases significantly ($p = 0.022$).

Conclusions. Patients with non-union and cage subsidence have less satisfactory clinical outcomes. The HU values of the vertebral bodies equal to 127 HU, 136 HU and 142 HU for the L4, L5, and S1, respectively, are advisable to use in practice to predict non-union and subsidence after a single-level decompression and stabilization intervention at the lower lumbar levels.

Key Words: Hounsfield units, HU, circumferential fusion, bone block, cage subsidence, bone density.

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Over the past few decades, the world has seen a trend towards an increase in the total number of decompression and stabilization interventions in the lumbar spine. The most common reason cited for this type of surgery is degenerative disease of spine [1]. Many studies have shown that decompression and stabilization interventions have a positive clinical outcome; up to 80 % of patients are satisfied with the treatment [2].

One of the main goals of decompression and stabilization interventions is the formation of a strong artificial bone-metal block [3, 4]. Nevertheless, in some cases, undesirable phenomena such as interbody non-union and implant subsidence occur in the postoperative period. They, by themselves, are insufficient indicators of the radiological outcome of decompression and stabilization treatment. There is no consensus to the question of the correlation of clinical and radiological outcomes of decompression and stabilization interventions. The authors' data is contradictory. Undoubtedly, poor radiological results cause anxiety and alertness in both of the doctor and the patient. Reduced bone mineral density (BMD) is one of the predictors of structural instability, interbody non-union, and, as a result, an increase in the number of reoperations [5–7].

Determination of the BMD of vertebrae in Hounsfield units (HU) promotes determination of the density of the cancellous bone, excluding cortical, in any vertebra, including L5 and S1, in contrast to the gold standard of densitometry. A low value of the BMD of the lumbar vertebral body in the HU values is an independent risk factor for interbody non-union and cage subsidence [8–10]. BMD expressed in HU has threshold values at which the probability of these adverse events increases significantly.

The values of the BMD of the vertebral bodies, equal to 122–135 HU, are threshold values to the occurrence of cage subsidence [10–13]. The values of the BMD of the vertebral bodies, equal to 107–166 HU, are considered threshold ones for interbody non-union at the lumbar level [14–16]. Despite the variety of the HU values obtained, these values were received in the analysis of heterogeneous patient cohorts: total values from fixations of different extents, different surgical techniques, and measurement of BMD. Each of the above features has its own risks of adverse outcomes. In this regard, it is complicated to extrapolate their practical application. Additionally, it should be noted that in most studies, opportunistic CT scans are used to evaluate threshold values and calculations are also performed on different vertebrae (L1, L3 vertebrae, and averaged values of L1–L4 vertebrae), regardless of the fusion level [9, 17, 18].

Since the most common decompressive and stabilization intervention techniques for degenerative diseases of the lumbar spine are TLIF and PLIF [19, 20], and the most frequently operated segments are the lower lumbar levels, the availability of specific practical guidelines on the methodology for determining the HU values of vertebral bodies and predicting the surgical outcomes becomes a necessity in vertebrology.

The objective is to determine the HU values of the lumbar vertebrae predicting unsatisfactory radiological results of single-level circumferential fusion at the lumbar level.

Material and Methods

The study is a retrospective analysis of the data of patients who underwent single-level circumferential lumbar fusion in 2012–2019. The study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the local Ethics Committee.

Inclusion criteria: a single-level screw transpedicular and interbody fixation of L4–L5 or L5–S1 segments with the use of a single PEEK cage; the presence of preoperative and postoperative CT scans of the lumbar spine. The following patients were not included in the study:

– who underwent a multi-staged procedure;

– with signs of intraoperative cage subsidence due to injury of the endplate according to X-ray examination performed immediately after the surgery;

– surgical revision in the early postoperative period;

– with infectious postoperative complications.

The surgical indication was vertebrogenic pain syndrome with or without neurologic impairment, with neurogenic intermittent claudication syndrome. A degenerative stenosis and/or degenerative spondylolisthesis in the lumbar spine served as the morphological substrate for clinical manifestations.

Techniques

Surgical intervention was performed in an open or minimally invasive manner (open TLIF, MIS TLIF) using one PEEK cage as an interbody graft without performing an additional posterior fusion. Autogenous bone was used as a filler for the cage. Cement augmentation was not performed in any case.

The following demographic variables were evaluated: age, gender, body mass index (BMI), and the predominant diagnosis. The clinical data included the scores of the VAS (back and leg) and ODI questionnaires assessed before surgery and at the follow-up examination.

The BMD of the vertebrae of the level to be stabilized was assessed in HU according to the preoperative CT scan of the lumbar spine. For this purpose, a region of interest (ROI) of the largest possible dimension was placed in three axial planes (immediately below the upper endplate, the mid-axial section, and just above the lower endplate) without the inclusion of the cortical bone. The HU values were defined by the software automatically; the data of a vertebra was averaged. Patients with the HU values in the lumbar spine less than 135 HU were categorized as patients with reduced BMD [9].

The correct position of the interbody graft was evaluated by X-ray of the lumbar spine immediately after surgery: the absence of intraoperative cage subsidence into the vertebral body and preservation of the integrity of the endplates.

The subsidence was identified on CT scans during a follow-up visit: the implant penetration into the adjacent vertebral body by more than 2 mm was evaluated [21]. The assessment of the formation of the interbody bone block was performed during a follow-up visit using CT scans in a binary system: unipolar and/or partial healing failure was regarded as an unformed interbody bone block (non-union), and complete bilateral adhesion was regarded as a formed block.

Using CT scans of the lumbar spine during the follow-up visit, the patients were divided into three groups:

1) patients with a formed interbody bone block and without implant subsidence (control group);

2) patients with interbody non-union and without implant subsidence; and

3) patients with implant subsidence and a formed interbody bone block.

Patients with a combination of non-union and interbody implant subsidence were excluded from the analysis due to the possible influence of many risk factors on the presence of such a combination.

Statistical analysis

The description of continuous data is presented in the form of MED [IQI]; binary data – in the form of quantity, % [95 % confidence interval]; categorical data – in the form of quantity in the category (%). Due to the small size of the groups, an intergroup comparison was performed using the Mann–Whitney U-test with the calculation of the value and 95 % CI for the pseudomedian of pairwise data differences as an appraisal of the mean data difference. The intergroup comparison of binary data was carried out by two-sided Fisher's exact test with an estimate of OR and 95 % CI for OR. To determine independent risk factors, a multidimensional logistic regression analysis was performed by systematically removing the least significant variables from the multiple logistic regression model, which initially included all variables. A significant difference was found to be $p < 0.05$. All calculations were done on the SPSS 15.0 software.

Results

Out of the total number of 1,193 patients who underwent a single-level decompression and stabilization intervention within the specified time frame and applied to the hospital again, 833 (69.8 %) were excluded due to the lack of necessary pre- and postoperative X-ray examinations, 58 (4.9 %) patients had infectious complications in the early postoperative period, and 45 (3.8 %) patients underwent surgical revision due to a residual compressing substrate and transpedicular screw malposition. As a result, the study included 257 (21.5 %) patients.

The duration of follow-up varied from 10 to 30 months; the median was 2.1 [1.8; 2.6] years. The incidence of non-union in re-treated patients was 32.3 % (83/257; Fig. 1); the incidence of subsidence of the interbody implant was revealed in 43.6 % (112/257) of patients (Fig. 2). The proportion of patients in the study cohort with reduced BMD was 26.1 % (67/257).

The patients reported a decrease in the intensity of back and leg pain and an improvement in functional capacity ($p > 0.05$) in the postoperative period. While comparing the parameters between groups, it was found that reintervention was performed by 2.3 times more often ($p = 0.037$) in patients with interbody non-union, and by 1.4 times more often ($p = 0.042$) in patients with subsidence in comparison with the control group. Additionally, in these groups, the proportion of patients with reduced BMD is higher ($p = 0.025$ and $p = 0.034$) and the average HU values of the vertebral bodies are lower ($p = 0.041$ and $p = 0.045$) in comparison with the control group.

Patients with resorption around screws were considerably more common in the group with interbody non-union ($n = 45$; 54.2 %) when compared with the subsidence group ($n = 38$; 33.9 %) and the control group ($n = 9$; 14.5 %); $p = 0.008$ and $p = 0.023$, respectively.

According to the questionnaires, patients with interbody non-union and subsidence have higher indicators of the functional capacity index ODI ($p = 0.045$ and $p = 0.050$) in comparison with the control group, and patients with subsidence have a tendency to more pronounced back pain according to VAS ($p = 0.051$). Other parameters, including demographic data and clinical indicators, have comparable values in the groups ($p > 0.05$; Table 1).

In patients with interbody non-union, lower HU values of all three vertebrae were identified ($p = 0.037$; $p = 0.044$; $p = 0.023$, respectively). As for patients with subsidence, then lower HU values of the bodies of the L5 and S1 vertebrae were noted ($p = 0.050$ and $p = 0.0041$, respectively; Table 2).

Interbody non-union and the implant subsidence are associated with reduced BMD ($r = 0.631$; $p = 0.005$ and $r = 0.750$; $p = 0.014$, respectively); with the HU values of vertebrae ($r = 0.721$; $p = 0.038$ and $r = 0.750$; $p = 0.008$, respectively); and with a higher ODI value ($r = 0.345$; $p = 0.032$ and $r = 0.402$; $p = 0.027$, respectively). Associations with other factors, including age, gender, BMI, and intervention level, did not indicate significance ($p > 0.05$).

According to the ROC analysis, the threshold HU values of vertebral bodies were established to identify patients with a high risk of interbody non-union and subsidence simultaneously. The threshold value of high sensitivity (>81 %) was determined at the levels of 125 HU, 139 HU, and 145 HU for the bodies of L4, L5, and S1 vertebrae, respectively ($p > 0.05$). The threshold value for high specificity (>88 %) was established at the level of 136 HU, 149 HU, and 157 HU for the bodies of L4, L5, and S1 vertebrae, respectively ($p > 0.05$). The balanced model (sensitivity > 78 %, specificity > 82 %) defined values of 127 HU, 136 HU, and 142 HU for the bodies of L4, L5, and S1 vertebrae, respectively, to predict the occurrence of a combination of interbody non-union and subsidence ($p = 0.022$).

Discussion

Though one of the goals of decompression and stabilization intervention is the formation of a strong artificial block, the unformed interbody block is quite frequent. In the study, we showed that the interbody non-union and implant subsidence correspond to the worst clinical outcome compared to other variants of X-ray patterns.

The prevalence of reduced BMD according to densitometry reaches 39.7 % among patients who require decompression and stabilization intervention [22]. Nevertheless, even among patients with normal densitometry parameters, the frequency of reduced BMD in the HU values according to CT scans is 25.9 % [22]. Patients with degenerative diseases of the spine have a higher incidence of undiagnosed spinal osteoporosis than in the general population, and the HU value, especially for such patients, more accurately reflects the BMD [18]. Moreover, the BMD in the HU values of the vertebral body is an independent predictor of complications, while the T-test is not [8, 14]. The proportion of patients in the study cohort with reduced BMD according to CT scans of the lumbar spine was 26.1 % (67/257), which is generally comparable with the literature data. The cohort under study is responsible for its lesser significance: the exclusion of patients with degenerative scoliosis and patients with multilevel fixation from the study.

Bone resorption around the screws was considerably more common in the group of patients with interbody non-union when compared with the other groups ($p = 0.008$ and $p = 0.023$, respectively). According to researchers [24], the interbody non-union is significantly more likely to occur in patients with resorption around the screws (43.0 % vs 2.6 %; $p < 0.001$) [23], and all this is associated with a reduced HU value of the vertebrae.

Patients with low HU values are more likely to have interbody non-union [9] and cage subsidence [11, 12]. In our study, patients with interbody non-union and subsidence showed a reduced BMD more often. In particular, interbody non-union is characterized by lower HU values in all three vertebrae, and subsidence is characterized by a reduced HU value in the L5 and S1 vertebrae.

According to our data, the frequency of interbody non-union is 32.3 % (83/257); the frequency of implant subsidence is 43.6 % (112/257). According to the literature data [25, 26], the frequency of interbody block formation varies from 22 to 100 %, and the frequency of interbody cage subsidence ranges from 10 to 35 % [26–28]. Such a wide range of values is caused not only by different perioperative parameters and types of interventions but also by different techniques

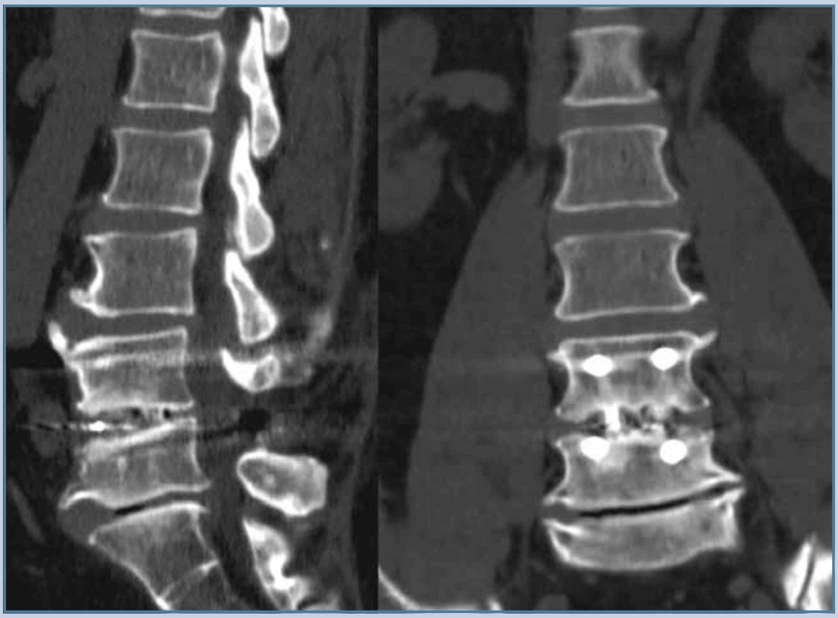

Fig. 1
CT scan of the lumbar spine: unformed bone-metal block of L4–L5 after transforaminal interbody fusion and transpedicular fixation at the level of L4–L5

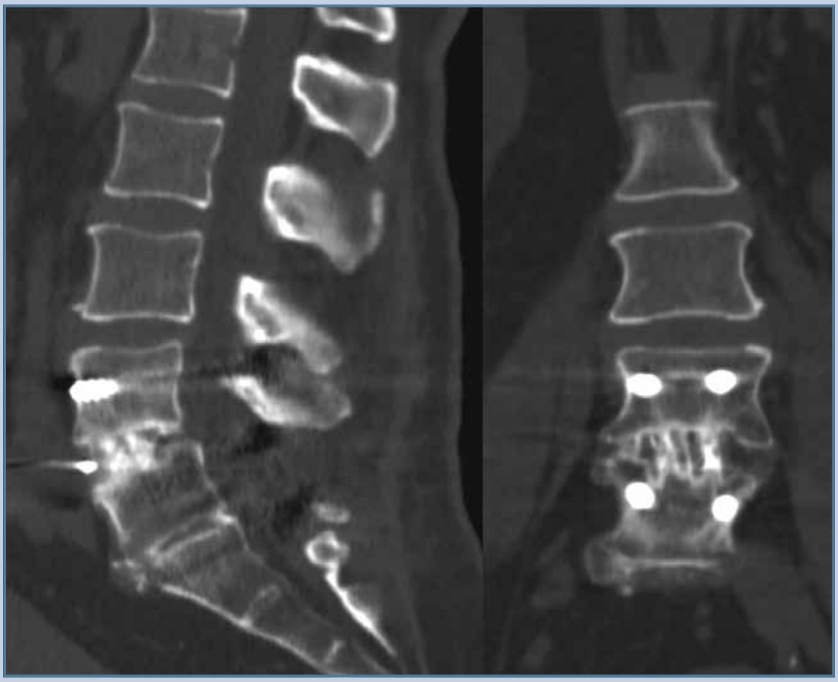

Fig. 2
CT scan of the lumbar spine: formed bone-metal block of L4–L5 after transforaminal interbody fusion and transpedicular fixation at the level of L4–L5; interbody implant subsidence

for evaluating these X-ray patterns. The authors receive data from different imaging techniques (X-ray, CT) and according to different classifications and scales (signs of instability, Bridwell and Tan scales, and others). Thus, CT examination of the lumbar spine has the best visualization capabilities, allowing a comprehensive estimation of the formation of the interbody block and cage subsidence [25]. It is also important to note that a CT examination should be performed before and after the procedure. Prior to surgery, it is required for planning intervention tactics, determining risk factors (including the HU values, establishing a reduced BMD), and predicting results. After surgery, this examination is vital for evaluating the outcomes (correct position of the implants, signs of bone block formation). Frequently, the possible harm from CT radiation is overestimated [29].

Intraoperative preparation of the endplate is more difficult in patients with low interbody space and an initially injured endplate due to degeneration. This can cause even greater injury of the endplate as well as implant subsidence during its insertion. Sparing manipulation with the preparation of the interbody space and the choice of the appropriate height of the cage can be valuable for the prevention of its intraoperative subsidence.

The impact of interbody non-union on clinical outcomes remains controversial. Some studies have found an adverse effect of interbody non-union on clinical outcomes [30, 31]. Makino et al. [30] reported that interbody non-union is a risk factor for a poorer quality of life of patients after surgery. Other researchers [32, 33] have shown comparable clinical outcomes in patients with formed block and with interbody non-union. Actually, immediately after surgery, the clinical picture improves in most patients due to decompression of neural structures. Nevertheless, in the long-term postoperative period, clinical symptoms often change and worsen [34]. The correlation between cage subsidence and clinical outcomes also remains controversial. Most studies [33, 35] have shown that cage subsidence is not associated with

Table 1

Intergroup comparison of clinical and radiological parameters of patients of the studied groups

Parameters	Control group (I), n = 62	Non-union group (II), n = 83	Subsidence group (III), n = 112	p-level		
				I vs II	I vs III	II vs III
Gender, n						
Men	13	22	23	0.893	0.721	0.653
Women	49	61	89	0.129	0.096	0.236
Age, years old	58.4 [49.2; 68.6]	66.7 [54.5; 69.9]	64.5 [51.2; 70.1]	0.235	0.635	0.741
Body mass index	29.7 [23.7; 34.5]	28.2 [24.1; 33.7]	27.6 [22.9; 31.8]	0.099	0.641	0.323
Surgical revision, n (%)	15 (24.2)	46 (55.4)	37 (33.0)	0.037	0.042	0.570
Mineral density of bone tissue						
Normal, n	55	56	79	0.642	0.090	0.720
Reduced BMD, n (%)	7 (11.3)	27 (32.5)	33 (29.5)	0.025	0.034	0.775
Average HU values of both vertebrae	178 [146; 205]	159 [137; 198]	164 [140; 189]	0.041	0.045	0.083
Intervention levels, n (%)						
L4–L5	40 (64.5)	46 (55.4)	64 (57.2)	0.090	0.541	0.738
L5–S1	22 (35.5)	37 (44.6)	48 (42.8)	0.632	0.090	0.027
Presence of resorption around screws, n (%)	9 (14.5)	45 (54.2)	38 (33.9)	0.023	0.325	0.008
Clinical data						
ODI before surgery	66 [37; 82]	64 [40; 81]	61 [39; 78]	0.088	0.082	0.077
VAS (leg) before surgery, points	8 [5; 9]	8 [4; 9]	8 [5; 9]	0.079	0.069	0.073
VAS (back) before surgery, points	7 [5; 9]	7 [5; 9]	7 [5; 8]	0.084	0.095	0.093
ODI after surgery	12 [8; 26]	22 [10; 34]	20 [12; 30]	0.045	0.050	0.088
VAS (leg) after surgery, points	0 [0; 1]	0 [0; 2]	0 [0; 1]	0.086	0.081	0.091
VAS (back) after surgery, points	2 [0; 3]	2 [1; 3]	3 [1; 4]	0.064	0.051	0.073

Table 2

The HU values of the vertebral bodies in study groups (p-value)

Vertebra	Main group (I)	Non-union group (II)	Subsidence group (III)	I vs II	I vs III	II vs III
L4	153 [121; 163]	137 [108; 159]	145 [112; 167]	0.037	0.057	0.067
L5	169 [134; 171]	144 [128; 168]	161 [134; 173]	0.044	0.050	0.071
S1	191 [164; 215]	178 [159; 191]	185 [154; 197]	0.023	0.041	0.052

clinical outcomes. Yao et al. [5] report that the ODI value in patients with subsidence is slightly higher at two-year follow-up and the difference between pre- and postoperative ODI values is considerably smaller. We have obtained similar data: a smaller regression according to the ODI questionnaire for patients with interbody non-union and cage subsidence, as well as a tendency to more pronounced back pain in the postoperative period in patients with subsidence ($p = 0.051$). A higher intensity of back pain may be the reason for the loss of segmental correction due to cage subsidence [36], which causes an impairment of the balance of the spinopelvic complex [37].

The BMD of the vertebrae in the lumbar spine is not the same. Nevertheless, there is no clear opinion about this: the authors refer to both a decrease in bone density to the underlying levels [18] and an increase in the BMD of the vertebrae from the superjacent to the subjacent levels [38]. There is also data on the absence of a significant difference in the HU values of the vertebrae of the lumbar spine; fluctuations in bone density are negligible [39]. Considering such a variety of data, it is essential to make a careful assessment of the density of L4–S1 vertebrae by the HU value of the body of the L1 vertebra or by other vertebrae not involved in stabilization [13, 14, 22], as recommended by the authors. There is a need to use different threshold values for the assessment of the BMD in different regions of the spine [40].

According to the literature data [41], the BMD of vertebral bodies in the case of a formed block is significantly higher when compared with cases of interbody non-union (203.3 vs 139.8; $p < 0.001$). Moreover, threshold values of bone density of vertebral bodies (122–135 HU) [10–12] have been defined, below which the probability of subsidence increases significantly. It is more appropriate to use a single threshold value to evaluate the risk of non-union, as well as cage subsidence, since both of these phenomena are undesirable. The constructed model showed threshold values for the bodies of L4, L5, and S1 vertebrae: 127 HU, 136 HU, and 142 HU, respectively, below which the risk of interbody non-union and implant subsidence will increase. The definition of these conditions is still relevant because they are associated with less satisfactory clinical outcomes. For our analysis, we took the most extended type of decompression and stabilization intervention (TLIF, MIS TLIF) and the two most frequently operated segments (L4–L5, L5–S1). We have received data that is advised for the routine practice of a spine surgeon.

Conclusion

The reduced BMD expressed in HU values is a risk factor for the occurrence of interbody non-union and cage subsidence when performing a single-level fusion. Patients with interbody non-union and cage subsidence have the worst clinical outcomes. In order to evaluate the risks of non-union, it is reasonable to perform a CT scan of the lumbar spine before surgery and to calculate the HU values for all patients with a planned decompression and stabilization intervention.

Limitations of the study:

1) the study cohort consisted of patients who, for some reason, applied to the hospital again; despite that follow-up examinations are recommended for all patients in the postoperative period, not all patients undergo them;

2) a PEEK cage filled with autogenous bone was used as an interbody implant, which may be reflected in the incidence of interbody non-union;

3) patients with resorption around the screws and those with a combination of three signs (interbody non-union, cage subsidence, and resorption around the screws) were not analyzed separately.

The research continues; the results will be reflected in the following papers.

The study had no sponsors. The authors declare that they have no conflict of interest.

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