SURGICAL TREATMENT OF KYPHOSIS DUE TO AVASCULAR OSTEONECROSIS OF THE VERTEBRAL BODIES

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Objective. To analyze the results of surgical treatment of patients with fixed spinal deformity due to osteonecrosis of the vertebral bodies of the thoracic and lumbar spine.

Material and Methods. The data obtained from the case histories of 40 patients operated on for kyphosis due to osteonecrosis of the vertebral bodies were studied. The patients underwent staged surgical interventions in one surgical session. Demographic data and radiological results of surgical treatment before surgery, after surgery and up to 1 year after surgery were assessed.

Results. As a result of surgical interventions, local kyphosis was corrected on average from 30° to -0.25°. After correction of kyphosis, statistically significant changes in the sagittal curves of the spine were revealed: an increase in thoracic kyphosis and a decrease in lumbar lordosis. There was an improvement in sagittal balance indicators in the form of a regression in the number of imbalanced patients — 17 (42.5 %) patients improved balance indicators. During the follow-up period, a statistically significant improvement in VAS and ODI scores was noted. Intra- and postoperative complications accounted for 35 %, and 8 (20 %) mechanical complications were identified during dynamic observation. Predictors of mechanical complications were the presence of imbalance: 2 and 3 points according to the balance modifier of the Formica classification and the GT index (global angle) > 7°, and insufficient correction of kyphosis (LK postOp > 4°), T-score index < -3.35.

Conclusion. Simultaneous staged surgical interventions allow for complete correction of the deformity, restoration of the sagittal profile, thereby improvement of the patient's quality of life. To reduce mechanical complications when planning and performing surgical intervention, it is necessary to take into account the identified predictors.

Key Words: aseptic necrosis, osteonecrosis of the vertebral body, K mel's disease, osteoporosis, circular stabilization, anterior spinal fusion, kyphosis, sagittal imbalance.

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Avascular osteonecrosis of the vertebral bodies (also known as Kummell's disease, delayed post-traumatic vertebral collapse, or ischemic vertebral collapse) is a clinical ischemic damage to the vertebral body characterized by complicated processes of resorption and regeneration that results in loss of the structural integrity of subchondral bone and manifests as the mechanical failure of vertebral bodies, and finally as their collapse. The pathogenesis of vertebral body osteonecrosis is based on the impaired blood supply as a result of injury, intravascular occlusion, and extravascular compression of bone vessels [1].

The most common etiology of bone osteonecrosis is injury that includes both a direct impact on the vertebral bone structure and an indirect effect caused by hemorrhage and swelling of the trabecular bone; considering the specific features of blood supply to the anterior third of the vertebral body, this leads to the extravascular compression of vertebral veins [2, 3]. There are reports on spontaneous osteonecrosis of vertebral bodies during the management of oncological diseases using cytotoxic chemotherapy or in the presence of viral infections; both these factors are non-traumatic causes of such development. Risk factors for Kummell's disease mentioned in literature sources include osteopenia/osteoporosis, diabetes mellitus, and rheumatic diseases [4].

Formica et al. [5] proposed a vertebral body osteonecrosis classification that indicates stages of the disease course and based on radiological findings (Table 1).

Stages 0–1–2 of osteonecrosis of the vertebral bodies are characterized by severe pain syndrome associated with acute instability. After the end of this period, that is, usually within 4–6 months after the disease onset, in the presence of the radiological pattern of vertebral collapse, a fixed local deformity is developed, often a gross one, accompanied by changes in both the physiological spinal curvatures and the spinopelvic and global sagittal balance, as well as by the decrease in patient quality of life. No such aspects are included in the Russian and international literature, however, they determine the significance of this pathology, as well as the objective of this research: analysis of clinical and radiological results of treatment for kyphotic spinal deformities resulting from avascular osteonecrosis of thoracic and lumbar vertebrae using the simultaneous staged surgical interventions.

Material and Methods

It was a cohort, retrospective, single-center research.

Inclusion criteria: patients with stage 3 osteonecrosis of the thoracic and lumbar vertebral bodies according to Formica et al. [5] who are able to independently maintain a standing position.

Exclusion criteria: post-traumatic kyphosis not associated with the aseptic necrosis of the vertebral bodies.

Of the 124 patients admitted in the clinic in 2020–2022, 40 patients with acquired post-traumatic spinal deformities met the inclusion criteria. The follow-up period was 1 year after the surgical intervention. Control points were the following: before and after surgery, 6 months after surgery, and 1 year after surgery.

The analyzed group included 33 female patients and 7 male patients. The age ranged from 30 to 74 years, the median was 64 [61; 67] years.

There is no evidence of injury in 15 (37.5 %) patients (Fig. 1); the onset of back pain was preceded by a low energy injury (fall) in 19 (47.5 %) patients; and only 6 patients reported a traumatic episode (road accident, work-related injury) followed by a spinal fracture and the corresponding conservative treatment. Kyphotic deformities were diagnosed within 6 to 11 months after the onset of back pain.

According to the Formica et al. classification [5], all patients were at the fixed deformity stage (stage 3). Significant vertebral body collapse and gross kyphosis (modifier A) were observed in 70.0 % of patients and latent or evident sagittal imbalance – in 52.5 % patients.

Patients were characterized by comorbidities, 35 of them had more than three comorbidities: Charlson comorbidity index [6] was mean 4 [3; 5] points, with 22 patients in the range 0–4 points, and 18 patients in the range of 5–8 points.

Six patients had vertebrogenic neurological symptoms due to spinal stenosis at the level of avascular osteonecrosis of the vertebra: 5 patients had compressive ischemic myelopathy (ASIA D), and 1 patient had polyradiculopathy due to cauda equina root compression; however, the patients retained their ability to maintain a standing position. Medical history data indicate a gradual development and worsening of neurological deficit.

All patients underwent staged surgical interventions in one surgical session. Kyphosis was managed using the technique of anterior spinal fusion followed by transpedicular fixation at the appropriate level. A specific feature of anterior approach in the presence of vertebral body collapse and spinal osteoporosis is patient's position on the back; kyphosis was carried out in a postural way after the vertebral body removal by adjusting the surgical table with the apex at the level of intervention, with no segment distraction manipulations. If compression of the spinal cord and its roots was detected, according to medical indications, anterior decompression was performed by removing the posterior part of the vertebral body, from pedicle to pedicle (Fig. 2, 3).

If there were spontaneous posterior bone blocks, facetectomy was performed as the preliminary stage. In these cases, the sequence of surgical stages was as follows: placement of instrumentation supporting elements (screws) and facetectomy – anterior spinal fusion – the instrumentation installation and additional correction of the deformity, if required.

We performed 7 three-stage and 33 two-stage surgical interventions, in total – 87 surgeries. Sixteen (40.0 %) patients underwent long-segment transpedicular fixation (5 vertebral segments), 24 (60.0 %) patients underwent short-segment fixation (3 segments). Screw augmentation with cement was performed in 25 (62.5 %) patients. Six patients with clinically significant spinal stenosis underwent anterior decompression during anterior intervention.

Total blood loss at all intervention stages was 300 [250.0; 512.5] mL (100–1,650 mL). Mean time of a surgical procedure (total time of all stages) was 300 [240.0; 346.2] min (190–600 min). We assessed registered intra- and postoperative complications according to the standardized Clavien–Dindo classification [7], as well as late mechanical com-

Table 1

Classification of avascular necrosis of the vertebrae according to Formica et al. [5]

Stage		Examination techniques	
0		Radiological images, MRI and CT without pathology	
1 "early stage"		Radiological images (-), CT (-), MRI (bone swelling)	
2 "instability stage"		Radiological images, CT (+) (vacuum symptom), MRI (+) (double circuit symptom)	
3 "fixed deformity stage"		Radiological images (+), CT (+) (vertebral collapse, fixed deformity), MRI (-)	
Modifiers			
Kyphosis (wedge index)		Values of sagittal balance indicators	
A	The ratio of the anterior and posterior vertebral body heights is more than 75%	1. Balance	SVA < 50 mm; PT ≤ thPT
		2. Latent imbalance	SVA < 50 mm; PT > thPT
B	The ratio of the anterior and posterior vertebral body heights is less than 75%	3. Imbalance	SVA > 50 mm; PT > thPT

SVA – spinal sagittal axis/sacral vertical axis; PT – patient pelvic tilt; thPT – theoretical pelvic tilt – proper PT (thPT= -0.7 + 0.37 PI – Vialle equation); classification = stage + angular kyphosis modifier + sagittal balance modifier (e.g. stage 3.A.2).

plications that included loss of correction of more than 10° during the follow-up period, and the presence of kyphosis (compression fracture) in the area adjacent to the fixation level.

To determine bone mineral density, we analyzed radiological densitometry data, T-score, and its interpretation based on the WHO classification of osteoporosis [8].

Parameters of pain and functional performance according to ODI and VAS scales were analyzed before and after surgery at the control points of the research.

Radiological parameters were assessed before and after surgery, as well as during control examinations using profile radiological images of the spine with the patient standing in standard position, in two standard views from the skull to the middle third of the femurs, with the hands placed on contralateral clavicles.

The following parameters of the spinal sagittal contour were analyzed: local kyphosis (LK) according to Cobb; thoracic kyphosis (TK) from the T4 body cranial plate to the caudal endplate of the vertebra superjacent to the damaged one; lumbar lordosis (LL) from the cranial endplate of the vertebra subjacent to the damaged one to S1. We measured the parameters of spinopelvic (PI, PT, SS) and global (SVA) balance and the global tilt (GT), i.e. the angle of intersection of the lines drawn through the center of the S1 vertebra from the femoral heads and the C7 vertebra [9]. We analyzed the subsidence of the anterior implant as a factor for the loss of correction of local kyphosis.

Statistical methods

Continuous variables in the analyzed group were tested for normality using the Shapiro-Wilk test and were presented as median values with interquartile intervals (MED [Q1; Q2]), arithmetic mean values ± standard deviations (M ± SD), minimum and maximum values (MIN – MAX). Binary and categorical variables were provided as the number of events with a rate of n (%). Continuous variables before and after surgery were compared using the Wilcoxon test. To assess a distribution shift, a pseudomedian (pMED) for paired differences was calculated; relative difference was determined using the standardized mean difference (SMD). The Formica categorical modifier 2 before and after surgery was compared using the McNemar's test. All tests used were two-sided. P values of less than 0.05 were considered significant. Predictors of mechanical complications were defined using logistic regression models. Pairwise associations were determined using univariate models, and multiple associations (predictors) were determined using multivariate models. Statistical hypotheses were assessed at a critical significance value $p = 0.05$, that is, the difference was considered statistically significant at $p < 0.05$. Calculations were carried out in IDE RStudio software (version 2023.09.1 Build 494 © 2009–2023 Posit Software, PBC, USA) using R (version 4.1.3).

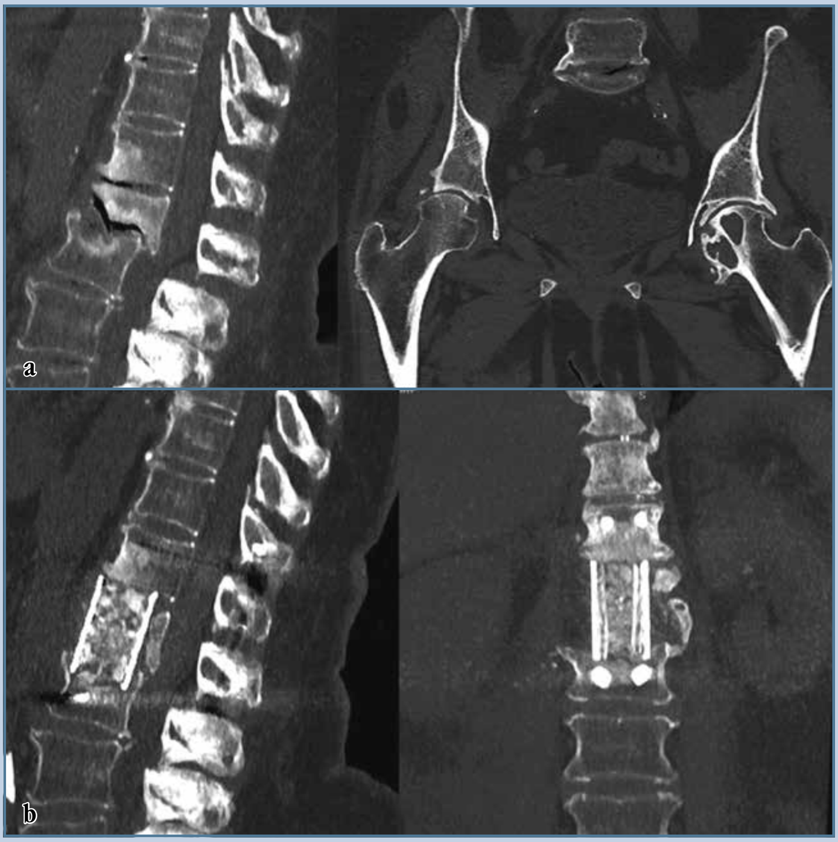

Fig. 1
MSCT of patient K., female, 64 years old: **a** – during examination for pain in the lower back and left hip joint, no underlying injury, avascular osteonecrosis of the L1 vertebra (stage 3.B.3) and avascular osteonecrosis of the left femoral head were revealed; **b** – the result of a simultaneous two-stage surgical intervention – anterior corrective spinal fusion, transcutaneous transpedicular fixation

Results

Post-traumatic thoracolumbar kyphosis (LK) was completely corrected during surgical interventions. After kyphosis correction, statistically significant changes were revealed in all sagittal spinal curvatures: increased thoracic kyphosis (TK) and decreased lumbar lordosis (LL). No statistically significant changes in spinopelvic and global sagittal balance were observed (Table 2). We

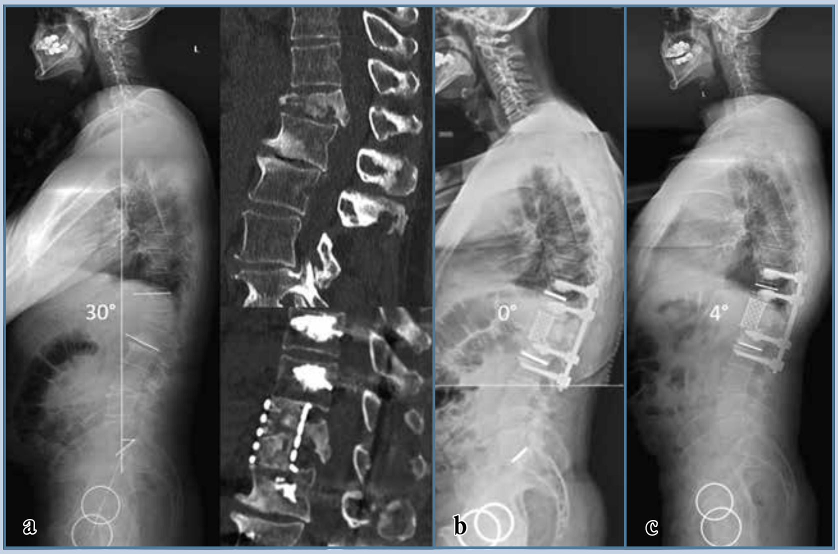

Fig. 2
Radiological images and MSCT of patient P., male, 62 years old: **a** – kyphosis associated with avascular osteonecrosis of the T12 vertebra (stage 3.A.2); **b** – the result of a simultaneous two-stage surgical intervention (anterior corrective spinal fusion and transpedicular fixation, screw augmentation), complete correction of the deformity was achieved; **c** – 1 year after surgery, correction of kyphosis was preserved, bone-metal block of the T11–L1 vertebrae was noted

identified a transition in the balance modifier (personalized PT and SVA) between its gradations before and after surgery: 47.5 % of patients had no signs of imbalance before surgery, and 70.0 % – after surgery. Changes in this transition over time are provided in the plot of interrelation of modifier changes (Fig. 4).

Changes in kyphosis during the follow-up period are shown in Table 3, and functional outcomes of patients is in Table 4.

Regression of neurological symptoms during postoperative follow-up was observed in two of six patients (transition to ASIA E).

Intraoperative and postoperative complications according to the Clavien–Dindo classification were registered in 14 (35 %) patients; any deviation from the normal postoperative period was considered (Table 5). Three patients had more than one complication.

Repeated surgical intervention was required in 1 case (2.5 %): revision of the right pleural cavity, anterior decompression, and repeated anterior spinal fusion were performed. This repeated surgery was required because of a neurological complication, i.e. preoperative motor deficit (distal monoparesis) that increased to right monoplegia. Other complications were resolved during patients' hospital stay.

Mechanical complications in 6 and 8 months after surgery were found in 8 (20 %) patients. It was kyphosis adjacent to fixation level associated with compression fractures of the vertebrae in three cases; kyphosis recurrence associated with subsidence of anterior implants into the bodies of adjacent vertebrae in four cases; and one case of late deep surgical site infection in more than 4 months after surgery; in this case, pseudoarthrosis and implant-associated infection developed in combination with gross kyphotic deformity. Subsequently, this patient underwent a successful staged reconstructive surgery in a specialized neurosurgical hospital in one of the Federal Healthcare centers of Russia.

Predictors of mechanical complications were incomplete kyphosis correction (LK postOp more than 4°) and global tilt value (GT preOp less than 7°), as well as the imbalance (2 and 3 points) according to the Formica classification. T-score value of less than -3.35 was also a predictor for the subsidence of anterior implants (Table 6).

Discussion

Avascular osteonecrosis of the vertebral body develops in middle-aged and elderly patients, usually associated with osteoporosis. New coronavirus infection cannot be excluded from the etiology of the analyzed disease, since the current social epidemiological situation is characterized by a widespread increase in bone osteonecrosis of all localizations [10, 11].

Formica et al. [4] developed a treatment-oriented classification of avascular osteonecrosis of the vertebrae. This classification is clinically useful for its clear designation of vertebral osteonecrosis stages in accordance with diagnostic criteria, as well as due to considering radiological parameters represented by modifiers (loss of vertebral body height/kyphosis), global sagittal balance (SVA) and spinal pelvic balance as PT personalized by PI. In accordance with the stage and significance of the modifiers, a functional configuration for treatment strategy was proposed [5]. Kyphosis modifier (ratio of the anterior and posterior height of less o more than 75 %) indicates a typical sign of osteonecrosis – a significant loss of anterior body height because of ischemic necrosis of the vertebral body in the anterior third, with relatively preservation of posterior body height. This feature visually (the caudoventral part of the body is more often affected) and radiometrically differentiates deformation of the vertebral body in osteonecrosis from osteoporotic fractures, for example, types OF4 and OF5, assessed according to the DGOU classification [12, 13]. Sagittal balance modifier indicates the classification of sagittal imbalance by Lamartina et al. [14] using the global balance parameter SVA, and

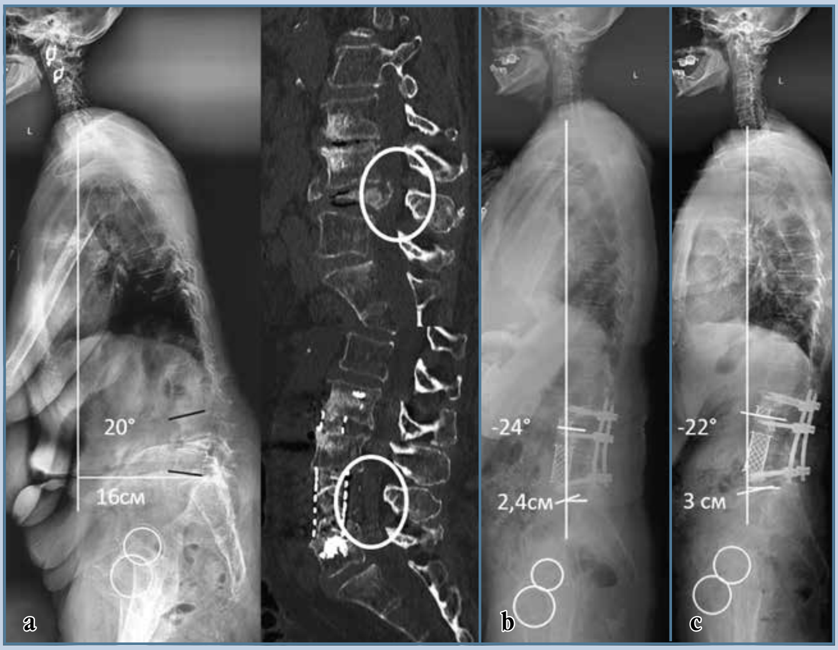

Fig. 3
Radiological images and MSCT of patient K., female, 72 years old, with kyphosis due to avascular osteonecrosis of the L4 vertebra (stage 3.A.3), compression of the roots of the cauda equina, polyradiculopathy: **a** – severe kyphosis of L3–L4, signs of global and spinopelvic imbalance, spinal stenosis; **b** – the result of a simultaneous two-stage surgical intervention (anterior decompression, anterior corrective spinal fusion of L2–L5 and transcutaneous fixation, screw augmentation), lumbar lordosis was restored, correction of global and spinopelvic balance parameters, decompression of the cauda equina roots was achieved; regression of neurological symptoms; **c** – 1 year after surgery, bone-metal block of L2–L5 vertebrae, correction of kyphosis was preserved

PI-personalized PT is a key parameter of spinopelvic balance that reflects compensatory pelvic retroversion [15, 16]. Moreover, increased PT may indicate pelvic retroversion not only for anatomical reasons (decreased lumbar lordosis), but also be a radiological sign of severe pain syndrome [17].

Current surgical strategy at the early stages of vertebral osteonecrosis include minimally invasive procedures that are aimed at stabilization of the affected segment by filling the vertebral bone defect (vacuum phenomenon, or intravertebral cleft) with cement during vertebroplasty, or kyphoplasty [18], or percutaneous transpedicular fixation with vertebroplasty [19, 20]. Not all cases of osteonecrosis result in critical local spine deformities. Moura and Gabriel [21] registered a case of spontaneous stabilization of post-traumatic spinal necrosis with osteophytes 4–6 months after conservative treatment.

If osteonecrosis is left untreated at the early stages, it results in vertebral body collapse, kyphotic deformity, and neurological deficit; all this is an indication for reconstructive surgery. Reconstruction of spinal anatomy and its physiological curvatures may be performed either by reconstructing the anterior column of the affected segment, or by osteotomy and reducing the posterior height of this segment.

We used simultaneous surgical intervention – corpectomy with circular stabilization. This technique allows reconstructing normal segmental ratios, correcting kyphosis, as well as carrying out complete decompression of the anterior sections of the spinal cord and its roots, if required. Ventral fixators used for osteoporotic spine according to indications were used in combination with long-segment fixation and cement augmentation of screws.

The applied surgical technique for postural kyphosis correction after corpectomy allows correcting local sagittal deformity of any grade. Radiological results of simultaneous staged surgeries demonstrated complete correction of post-traumatic deformity (from 30° to -0.25°) and regression of compensatory changes in spinal curvatures adjacent to kyphosis: increased thoracic kyphosis and decreased lumbar lordosis were observed. In anterior interventions for vertebral osteonecrosis, Wang et al. [22] registered residual postsurgical kyphosis of 7.6 ± 5.5° after surgery; Kanayama et al. [23] – 12.5°, and Kashii et al. [24] – 15.3 ± 8.1°. The achieved kyphosis correction underwent changes during follow-up; however, one year after surgery, kyphosis in the surgical site averaged to 5.8° [-4°; 40°], although the literature sources describe kyphosis with similar interventions during the follow-up period ranged from 9.9° to 26.8° [22–24]. The authors associate loss of correction and kyphosis recurrence with anterior interventions with underlying osteoporosis.

Despite the absence of statistically significant changes in the spinopelvic and global sagittal balance, the postoperative evaluation of the analyzed group revealed an improvement in the parameters of the Formica balance modifier in 14 (35 %) patients.

The volume of blood loss, as well as surgery duration in this research was within the values mentioned in literature sources [22–24].

The Clavien – Dindo classification was used to assess complications; it demonstrated that the most severe complication in the analyzed group was a neurological complication

Table 2

Comparison of sagittal curves of the spine, global and spinopelvic balance before and after surgery (n = 40)

Indicator	Before surgery MED [Q1; Q3] M ± SD (MIN – MAX)	After surgery MED [Q1; Q3] M ± SD (MIN – MAX)	Difference pMED [95 % CI] SMD [95 % CI]	Wilcoxon test, p value
LK	30.0 [25.00; 34.00] 30.10 ± 6.83 (20–52)	0.0 [-3.25; 2.25] -0.25 ± 8.00 (-28–22)	30.00 [30.00; 30.50] 4.08 [3.30; 4.85]	<0.001*
TK	31.0 [22.25; 38.25] 31.30 ± 14.56 (8–79)	39.0 [34.00; 46.00] 40.65 ± 10.49 (22–85)	-9.50 [-9.50; -9.00] -0.74 [-1.19; -0.28]	<0.001*
LL	-63.0 [-67.75; -57.00] -62.42 ± 14.08 (-90– -3)	-57.5 [-60.00; -52.00] -56.17 ± 8.39 (-79– -39)	-7.00 [-7.50; -7.00] -0.54 [-0.99; -0.09]	<0.001*
PT	16.0 [10.75; 21.00] 16.05 ± 7.84 (0–33)	14.5 [9.00; 20.00] 14.45 ± 7.83 (-2–32)	1.50 [1.00; 1.50] 0.20 [-0.24; 0.64]	0.064
SS	35.5 [30.00; 39.25] 35.12 ± 7.69 (17–56)	36.0 [34.00; 39.25] 37.00 ± 6.73 (15–52)	-1.50 [-2.00; -1.50] -0.26 [-0.70; 0.18]	0.053
SVA	1.5 [-0.50; 3.80] 1.97 ± 3.94 (-4– -15)	1.0 [-1.00; 2.30] 1.62 ± 6.95 (-6–40)	1.00 [0.75; 1.10] 0.06 [-0.38; 0.50]	0.118
GT	15.5 [9.00; 23.50] 16.92 ± 10.88 (0–52)	12.5 [7.00; 18.25] 13.72 ± 9.39 (-1–35)	2.00 [2.00; 2.50] 0.31 [-0.13; 0.76]	0.047
Sagittal balance modifier	1: 19 (47.5 %) 2: 14 (35.0 %) 3: 7 (17.5 %)	1: 28 (70.0 %) 2: 10 (25.0 %) 3: 2 (5.0 %)	–	0.074+

* p < 0.001; + comparison by McNemar's test.

Table 3

Changes over time in kyphosis during the follow-up period

LK preOp, degree	LK postOp, degree	LK postOp 6 months, degree	LK postOp 12 months, degree
MED [Q1; Q3] M ± SD (MIN – MAX)	MED [Q1; Q3]* M ± SD* (MIN – MAX)	MED [Q1; Q3] M ± SD (MIN – MAX)	MED [Q1; Q3] M ± SD (MIN – MAX)
30 [25.00; 34.00] 30.10 ± 6.83 (20–52)	0 [-3.25; 2.25]* -0.25 ± 8.00* (-28–22)*	2 [0.00; 5.75] 4.03 ± 11.13 (-26–44)	4 [0.75; 8.00] 5.82 ± 12.11 (-26–44)

*p < 0.001.

(n = 1; 2.5 %) that required repeated intervention (3b). Complications and deviations from the normal postoperative period (including coronavirus infection) were resolved during hospital stay and amounted to 35 %, and this value is less than, for example, complications of three-column osteotomies performed for the management of degenerative imbalance in patients with comparable age and quality of health [25].

Late mechanical complications (n = 8; 20.0%) included loss of correction of more than 10° (n = 5) associated with implant subsidence and the development of compression fractures (n = 3) of the vertebrae superjacent or subjacent to the fixation zone. Revision staged surgery was required in one patient for an implant-associated infection, pseudarthrosis, and kyphosis recurrence up to 40°; it resulted in debridement of infected area and complete stable correction of the deformity. Uchida et al. [26] reported mechanical complications in 11 (36 %) of 30 patients (2 adjacent fractures, 9 cases of screws loosening in anterior instrumentation and cage subsidence). Kanayama et al. [23] registered 7 frac-

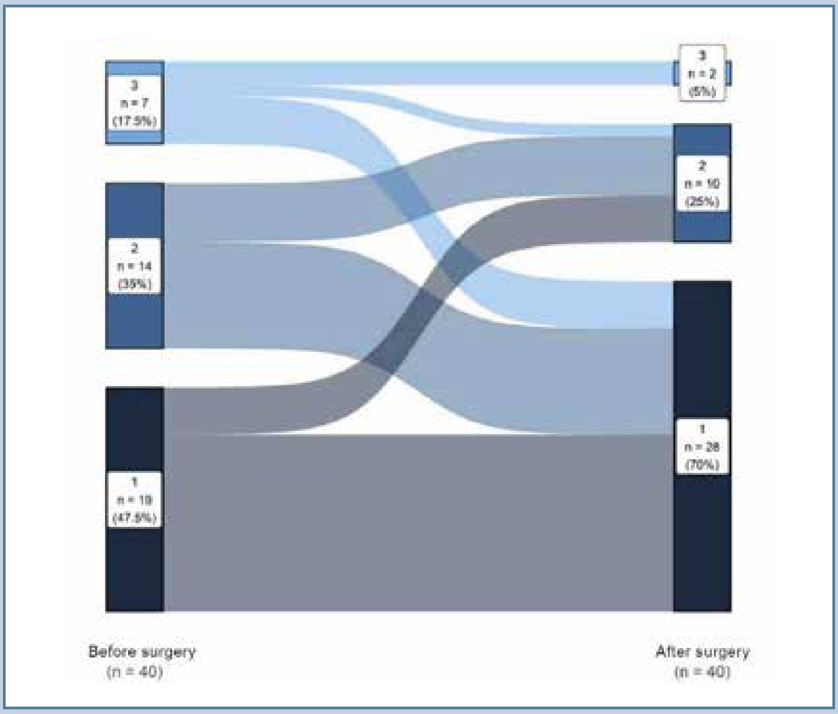

Fig. 4
Plot of the sagittal balance modifier transition before and after surgery (n = 40)

tures of adjacent vertebrae and 6 cases of kyphosis progression in a group of 31 patients [23].

This research revealed that predictors of mechanical complications are insufficient correction of kyphosis (LK postOp more than 4°), significant simultaneous correction of kyphosis (ΔLK more than 37.5°), and T-score less than -3.35. Moreover, integral parameters of sagittal balance turned out to be predictors of mechanical complications: imbalance (2 and 3 points) according to the balance modifier of the Formica classification and GT value (global tilt) more than 7°. The extent of posterior fixation, the presence/absence of screw augmentation, and vertebral ROI had no effect on the development of mechanical complications.

The advantage of anterior corrective interventions is their greater potential for kyphosis correction (ΔLK more than 37.5°); however, this is also the disadvantage: complete correction of gross kyphosis to the required values with underlying severe osteoporosis leads to implant subsidence despite posterior fixation and cement screw augmentation. It seems that an alternative type of reconstructive surgery, that is, spinal osteotomy, should be preferred for the surgical management of gross kyphotic deformity of more than 37.5° in the presence of severe spinal osteoporosis and signs of imbalance.

Parameters of pain and functional performance in the analyzed group statistically significantly improved ($p < 0.001$) during the follow-up period.

Table 4
Changes over time in quality of life indicators during the follow-up period

Indicator	Before surgery	6 months after surgery	12 months after surgery
	ODI		
MED [Q1; Q3]	54 [34.0; 70.0]	32 [25.0; 48.0]*	30 [22.0; 45.0]
M ± SD	54.2 ± 12.1	32.4 ± 9.3*	30.2 ± 4.2
(MIN – MAX)	(30–80)	(10–50)	(10–45)
	VAS		
MED [Q1; Q3]	5 [3.2; 7.0]	3 [2.0; 3.8]*	2 [1.5; 3.1]
M ± SD	4.8 ± 1.8	2.5 ± 1.6*	2.1 ± 1.4
(MIN – MAX)	(2–7)	(1–5)	(1–5)

*p < 0.001.

Conclusion

Results of the surgical management of kyphosis associated with avascular osteonecrosis of the vertebral bodies using simultaneous staged surgical intervention are characterized in the analyzed group by complete kyphosis correction, improved sagittal balance parameters, pain parameters, and functional performance during the follow-up period. The limitations of this method, i.e. predictors of mechanical complications, should be used when planning surgical interventions.

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committees of the institutions. All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

Table 5

Intraoperative and postoperative complications

Complications	Grade according to Clavien – Dindo	Number, n (%)
Neurological (motor deficit)	3b	1 (2.5)
– Non-infectious:		
– atelectasis requiring follow-up in the ICU	2	2 (5.0)
– pneumothorax	2	1 (2.5)
– atrial fibrillation	2	3 (7.5)
– anemia requiring transfusion	2	3 (7.5)
– thrombosis of the lower extremities veins	1	1 (7.5)
– perioperative plexopathy	1	1 (2.5)
– Infectious:		
– new coronavirus infection (COVID-19)	1	3 (7.5)
– hospital-acquired pneumonia		
– early superficial infection of the area of	2	2 (5.0)
surgical intervention	2	1 (2.5)
Total	17	

Table 6

Covariate values in logistic regression models for mechanical complications (n = 8)

Covariates	Univariate models		Multivariate models	
	OR [95 % CI]	p	OR [95 % CI]	p
LK postOp > 4°	0.02 [0.00; 0.13]	<0.001*	0.02 [0.00; 0.14]	0.001*
T-score < -3.35	0.13 [0.02; 0.92]	0.039*	23.76 [0.70; 7890.13]	0.127
GT preOp < 7°	7.47 [1.29; 49.42]	0.026*	–	–
Modifier 2 according to Formica	0.21 [0.03; 0.79]	0.049*	–	–

* $p < 0.05$.

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