VARIANTS OF TITANIUM MESH IMPLANT PENETRATION INTO THE LUMBAR VERTEBRAL BODIES AFTER ANTERIOR FUSION

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Objective. To assess radiological results of anterior spinal fusion using cylindrical titanium mesh implant for lumbar spine fracture.
Material and Methods. A total of 74 adult patients with unstable fractures of the L1—L5 vertebral bodies were selected. They underwent posterior instrumental fixation, anterior decompression of the spinal cord and its roots, and anterior interbody fusion with placement of titanium mesh implant. Radiological and CT control was performed immediately and 0.5—2 years after surgery.
Results. The phenomenon of implant penetration into the body/bodies of the cranial and/or caudal fused vertebrae has been revealed. Depending on the nature of penetration, single-level (into one vertebra) and two-level (into two vertebrae) variants of the implant edge penetration were identified. A method for calculating the penetration rate was developed, which value determines three grades of the implant penetration: grade 1 with a rate less than 0.1; grade 2 — 0.1—0.29; and grade 3 — more than 0.3. On this basis, the results of anterior spinal fusion are evaluated as good, satisfactory or unsatisfactory, respectively. If the implant did not penetrate, the result is considered excellent.
Conclusion. The proposed rate of implant penetration allows for objective evaluation of the interbody fusion results, both immediate and long-term.
Key Words: vertebral fractures, anterior fusion, titanium mesh implant, rate and grade of implant penetration.

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Currently, anterior reconstruction with cylindrical titanium mesh implants is widely used to treat injuries and diseases of the spine [1, 3—7, 11, 12, 14]. The implant provides a relatively rapid recovery of the supporting ability of the anterior spinal column. It can be used in combination with fixators required for stabilization of the operated segment [8, 16, 19—21]. The cage is filled with autobone chips made from the resected vertebral body or material of the iliac crest and rib. Allobone is also used [10]. The bone block is formed within the period from 6 to 12 months after the operation [20, 22, 23].

A subsidence of the mesh implant into the spongy bone tissue of the vertebra is observed during bone block formation [9, 17, 22]. This phenomenon is poorly understood, and for this reason we analyzed anterior interbody fusion operations for lumbar vertebral fractures. Medical and biological effect achieved using mesh implants is based on providing conditions for organ-preserving technique of anterior interbody fusion in the lumbar spine [4, 13, 18].

Autologous bone has properties required for fusion: osteogenicity, osteoinductivity, and osteoconductivity. The autograft contains morphogenetic proteins, mineral constituents, and some amount of osteoblasts. These properties are the most characteristic of spongy bones, which, however, have insufficient mechanical strength, whereas anterior interbody fusion requires high mechanical strength of the graft.

The study was aimed at analyzing the radiographic results of anterior interbody fusion for lumbar vertebral fractures using cylindrical titanium mesh implants.

Material and Methods

A total of 356 operations for anterior interbody fusion in all segments of the spine were carried out in 2009–2016. The study included 74 patients aged 15–56 years (20 males, 54 females) with unstable fractures of lumbar vertebral bodies (burst fracture of L1–L5 vertebrae), who underwent anterior decompression of the spinal cord and nerve roots, as well as interbody anterior corporodesis using a titanium mesh implant. The cage was filled with autologous bone fragments with a cortical layer.

To approach the L1 vertebra, thoracophrenolumbotomy was used (combined transpleural-retroperitoneal approach with diaphragm dissection). Extraperitoneal lumbotomy was used to approach the vertebrae below this level. Intraoperative X-ray with labelling of the vertebra or disc with a needle was carried out to verify the operation level. When removing intervertebral discs adjacent to the injured vertebra, we tried to preserve intact endplates, since we considered this an important condition for stability of the spine after implant insertion.

All 74 patients underwent two-staged surgery: the first stage including posterior instrumental, predominantly transpedicular fixation was performed on day 2–4 after admission, and the second stage inluding combined anterior fusion with implant filled with autologous bone was carried out in 12–14 days.

The required types and sizes of the implant were determined depending on the level of fracture and size of fused vertebral bodies (Table 1). Implants of 16, 19, or 22 mm in diameter were typically used for corporodesis and reliable anterior stabilization in the lumbar spine.

The results were analyzed using X-ray examination immediately after surgery, as well as in 6, 12, and 24 months. When analyzing the characteristics of fusion mass over time according to the data of survey radiographs in the lateral projection or CT scan through the vertical central axis of the implant, we assessed its position, as well as the depth of penetration of its edges into the superjacent and subjacent fused vertebrae. If the implant did not penetrate into the bodies of adjacent vertebrae, the result of fusion was rated as excellent, these patients were not included in the study group of penetration phenomenon. On images where implant penetrated into the vertebral bodies, the reference points were placed at the edges of the vertebral bodies and the implant, and connected by lines along the perimeter, followed by measurement of the length of the resulting lines, the perimeters of the quadrangles or triangles formed by these lines in the vertebral bodies adjacent to the implant.

Results and Discussion

The analysis of X-ray data revealed the phenomenon of mesh cage penetration into the body/bodies of the fused vertebrae, which was either single-level (superjacent or subjacent vertebra) or two-level. Several variants were identified depending on the shape of penetrated implant edge (triangular or quadrangular; Fig. 1).

1. Single-level penetration:

1.1. – triangle-shaped into the cranial vertebra;

1.2 – quadrangle-shaped into the cranial vertebra;

1.3 – triangle-shaped into the caudal vertebra;

1.4 – quadrangle-shaped into the caudal vertebra.

2. Two-level penetration:

2.1 – in the form of two triangles into the cranial and caudal vertebrae;

2.2 – in the form of two quadrangles into the cranial and caudal vertebrae;

2.2 – in the form of a triangle into the cranial vertebra and quadrangle into the caudal vertebra;

2.4 – in the form of a quadrangle into the cranial vertebra and triangle into the caudal vertebra.

Penetration of mesh implant edges into vertebral bodies adjacent to the implant were evaluated; the results assessed immediately after surgery are shown in Table 2; the results in the long-term postoperative period – in Table 3.

Most patients had penetration types 1.4 (27.0 %) and 2.2 (26.3 %), i.e. implant penetration into subjacent vertebra in the form of a quadrangle or two-level penetration of the implant in the form of two quadrangles. The areas of the resulting geometric figures, the rectangle of the implant and its penetrated parts, the quadrangle and triangle [15], were calculated to assess and quantify implant penetration into the vertebral bodies. The coefficient of mesh implant penetration into the bodies of adjacent vertebrae was calculated according to the formula:

$K = (S_1 + S_2)/S$,

where K is implant penetration rate; S_1 and S_2 — the areas of the upper and lower penetrated areas (quadrangle or triangle); S — the area of the rectangular shadow of the implant. Three grades of implant penetration into the vertebral bodies were identified depending

Таблица 1

Parameters of cylindrical titanium mesh implants

Parameters	Standard size										
Diameter, mm	10	12	13	15	16	18	19	21	22	23	25
Length*, mm	50 to 100										
Weight, g	3.0	3.5	4.0	4.5	5.5	7.0	8.0	10.0	11.0	12.0	14.0
Wall thickness, mm	1.0 to 1.2										

*implant length is adjusted intraoperatively.

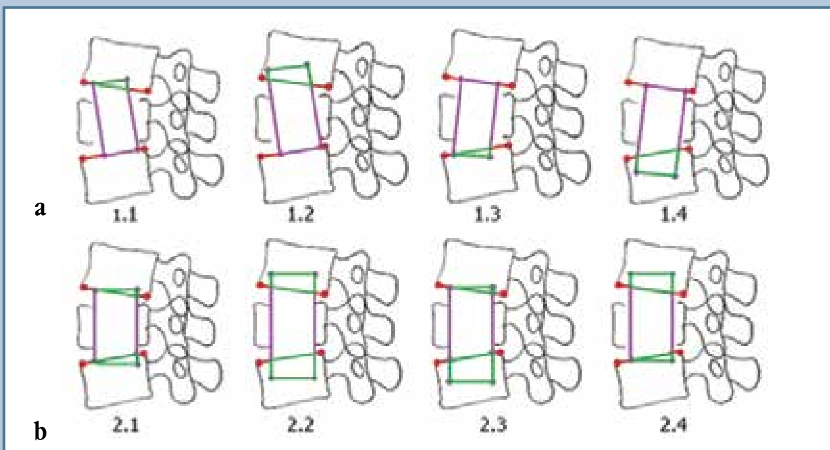

Fig. 1
Variants of cylindrical titanium mesh implant penetrations into the vertebral bodies adjacent to the injured vertebra: **a** — single-level; **b** — two-level

on the implant penetration rate: grade 1 — K < 0.1 (mild penetration); grade 2 — K = 0.1–0.29 (moderate penetration); grade 3 — K > 0.3 (severe penetration).

In the case of grade 1 implant penetration, the result was rated as good, grade 2 — satisfactory, further dynamic long-term follow-up is required, grade 3 — unsatisfactory, associated primarily with osteoporosis of the spine and the need for its adequate treatment [11].

When assessing the results (Tables 2, 3) of 74 studies, grade 1 implant penetration was found in 34 (46 %) patients, grade 2 in 32 (43 %) patients, and grade 3 in 8 (11 %) patients. In the case of single-level penetration, the coefficient typically corresponded to grade 1, and K exceeded 0.1 only in two patients. In the case of two-level implant penetration, grade 2 was observed in 28 (74 %) cases, grade 1 in 2 (5 %) cases, and grade 3 in 8 (21 %) cases.

Table 2

Variants of cylindrical mesh implant penetration into the vertebral bodies adjacent to the implant in the early postoperative period

Variants of implant penetration into the vertebral body	Patients, n (%)
Single-level	
Triangle-shaped penetration of the upper end of the implant	3 (10)
Quadrangle-shaped penetration of the upper end of the implant	5 (15)
Triangle-shaped penetration of the lower end of the implant	4 (12)
Quadrangle-shaped penetration of the lower end of the implant	9 (27)
Two-level	
Penetration of the implant into the superadjacent and subadjacent vertebral bodies in the form of two triangles	1 (3)
Penetration of the implant into the superadjacent and subadjacent vertebral bodies in the form of two quadrangles	5 (15)
Penetration of the upper end of the implant in the form of triangle and lower end of the implant in the form of quadrangle	6 (18)
Penetration of the upper end of the implant in the form of quadrangle and lower end of the implant in the form of triangle	–

The first operation – instrumental posterior fixation; the second operation – anterior fusion with implant insertion

Table 3

Variants of cylindrical mesh implant penetration into the vertebral bodies adjacent to the implant 0.5–2 years after the operation

Variants of implant penetration into the vertebral body	Patients, n (%)
Single-level	
Triangle-shaped penetration of the upper end of the implant	–
Quadrangle-shaped penetration of the upper end of the implant	4 (9.4)
Triangle-shaped penetration of the lower end of the implant	2 (4.8)
Quadrangle-shaped penetration of the lower end of the implant	7 (16.8)
Two-level	
Penetration of the implant into the superadjacent and subadjacent vertebral bodies in the form of two triangles	6 (14.3)
Penetration of the implant into the superadjacent and subadjacent vertebral bodies in the form of two quadrangles	11 (26.3)
Penetration of the upper end of the implant in the form of triangle and lower end of the implant in the form of quadrangle	8 (19.2)
Penetration of the upper end of the implant in the form of quadrangle and lower end of the implant in the form of triangle	3 (7.2)

The measured values of the parameters of geometric figures and penetration rate of titanium mesh implants in 15 patients with type 2.2 penetration are summarized in Table 4.

Implant penetration into the bodies of adjacent vertebrae can be caused by the following factors: patient's overweight, highly developed musculature, damaged (defective) endplate at the site where the end of the implant is positioned, local perifocal bone resorption caused by the implant, osteopenia (osteoporosis) of the spine. An important role is played by a small supporting area of the ends of the implant, whose wall thickness is only 1–1.2 mm.

Case study. Patient A. was admitted 6 months after anterior decompression of the spinal cord at the level of L2, anterior fusion of L1–L3 vertebrae using cylindrical titanium mesh implant with autologous bone fragments with a cortical layer, and additional fixation of L1–L3 vertebrae with a titanium plate. CT showed correct position of the implant and consolidation stage of the fracture. Landmarks are labelled on the images (Fig. 2, 3): points 1, 2, 3, 4 are located at the edges of L1–L3 vertebral bodies, points 5, 6, 7, 8 are located at the ends of the implant; 5, 6, 9 – along the perimeter of the upper triangle; 7, 8, 12, 11 – along the perimeter of the lower quadrangle, in L3 vertebral body.

The points were connected along the perimeter (1–2, 3–4, 5–6, 7–8, 5–8, 6–7) followed by measurement of the length of the resulting lines (9–5, 5–6, 6–10, 10–9, 8–12, 12–11, 11–7, 7–8, 5–8, 5–6, 6–7; 7–8) and calculation of the areas of the geometric figures. Triangle-shaped penetration of the upper end of the implant and quadrangle-shaped penetration of the lower end, which corresponds to type 2.3, was observed

Table 4
A variant of mesh implant penetration into the vertebral body (two-level quadrangle-shaped penetration)

Rectangle of the implant			Upper quadrangle						Lower quadrangle						Coefficient	Implant penetration grade
Side length, mm		Area, mm²	Side length, mm				Semiperimeter, mm	Area, mm²	Side length, mm				Semiperimeter, mm	Area, mm²		
25	54	1350	25	24	6	3	29.0	109.3	25	24	11	7	33.5	219.4	0.24	2
20	43	860	20	4	20	4	24.0	80.0	20	4	21	6	25.5	101.9	0.21	2
20	43	860	20	8	21	7	28.0	153.3	20	4	21	7	26.0	112.0	0.30	3
20	43	860	20	6	21	4	25.5	101.8	20	4	21	5	25.0	91.7	0.22	2
17	47	799	17	3	17	3	20.0	51.0	17	5	14	7	21.5	89.8	0.17	2
17	47	799	17	7	18	3	22.5	86.4	17	4	18	9	24.0	112.2	0.24	2
27	50	1350	27	12	25	6	35.0	230.9	27	10	28	9	37.0	260.8	0.36	3
20	22	440	20	6	18	4	24.0	92.9	20	9	19	7	27.5	155.5	0.56	3
27	67	1809	27	10	26	9	36.0	251.3	27	11	25	5	34.0	205.0	0.25	2
20	45	900	20	2	20	2	22.0	40.0	20	8	19	6	26.5	136.0	0.19	2
20	45	900	20	7	19	5	25.5	116.4	20	6	20	9	27.5	149.6	0.29	2
20	35	700	20	5	19	6	25.0	106.8	20	9	20	11	30.0	199.7	0.43	3
25	43	1075	25	7	26	11	34.5	228.4	25	6	25	6	31.0	150.0	0.35	3
25	43	1075	25	14	26	11	38.0	317.9	25	7	25	7	32.0	175.0	0.45	3
20	40	800	20	6	23	2	25.5	79.38	20	8	21	4	26.5	122.0	0.25	2

immediately after surgery (Fig. 2). In the long-term period (Fig. 3), both ends of the implant penetrated in the form of two quadrangles (type 2.2). The calculated K = 0.42 corresponds to grade 3 implant penetration into L1 and L3 bodies, which is an unsatisfactory outcome of the reconstructive operation due to osteoporosis of the spine (it was verified by osteodensitometry and treatment was prescribed).

Conclusions

1. The phenomenon of cylindrical titanium mesh implant penetration into the body/bodies of the cranial and/or caudal vertebrae was found as exemplified by unstable fractures of the lumbar vertebral bodies.

2. Eight variants of implant penetration were identified.

3. The method for calculating the rate of titanium mesh implant penetration

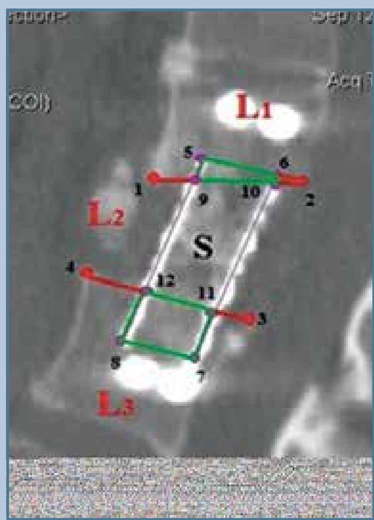

Fig. 2
CT of patient A. in the early postoperative period: L1, L3 – vertebral bodies; *1, 2, 3, 4* — vertebral endplates; *5, 6, 9* — triangle of the upper end of the implant in L1 vertebral body; *7, 8, 12, 11* — quadrangle of the lower end of the implant in L3 vertebral body

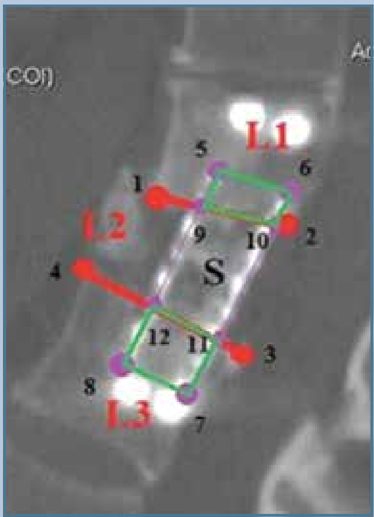

Fig. 3
CT of patient A. in the long-term postoperative period: *5, 6, 10, 9* — quadrangle of the upper end of the implant in L1 vertebral body; *7, 8, 12, 11* — quadrangle of the lower end of the implant in L3 vertebral body; the progression of implant penetration into the body of the cranial vertebra is observed

into the vertebral bodies and the criteria for its differentiation was, which allow objective evaluation of both immediate and long-term postoperative results of interbody fusion.

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