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BROKEN RODS IN SPINAL DEFORMITY SURGERY: AN ANALYSIS OF CLINICAL EXPERIENCE AND A LITERATURE REVIEW

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Background. Rod fractures are one of the specific complications of spinal deformity surgery. The number of publications on this topic is small, and the conclusions are often contradictory.
Aim. The aim of this study is to analyze the current situation concerning the problem of fractures of the rods in spinal deformities of various etiologies in terms of frequency and risk factors for this complication.
Materials and methods. The study included 3,833 patients who underwent operations between 1996 and 2018. The inclusion criteria of being over 10 years of age with no history of spinal surgery were applied.
Results. Fractures of metal implant rods were detected in 85 patients out of a total of 3,833 (2.2%). There was a significant difference between the groups of idiopathic and congenital scoliosis patients. A rod fracture in 62 of the 85 patients was the reason for reintervention to restore integrity with a connector or a full replacement. An increase in BMI by one raised the chance of a fracture by 1.07 times ($p = 0.019$). Increasing the age by one year increased the possibility of a fracture by 1.03 times ($p = 0.039$). A statistically significant association of the ventral stage of surgical treatment (discectomy and interbody fusion with autologous bone) where no fracture was detected ($p = 0.403$) was revealed. Being over 15 years old a statistically significant predictor was in the group under 20 years of age ($p = 0.048$). For BMI, there was no statistically significant threshold for fracture probability in the group under 20 years of age. It was confirmed that a hybrid fixation system produced a significantly lower percentage of complications than a hook system. A systematic literature review of sources on this topic included international databases (Scopus, Medline, and Google Scholar) as well as investigating the publications contained in the reference list.
Conclusions. Rod fractures during surgery for spinal deformities of various etiologies are one of the typical complications. Fracture frequency in large study groups is small. The risk of developing this complication rises with both increasing BMI and patient age, although there is no statistically significant threshold for BMI relative to the chances of fracture in the group up to 20 years of age. Modern reticular systems of attachment of the endocorrector to the vertebral structures can dramatically reduce the risk of rod fracture during the postoperative period.

Keywords: spinal deformities; surgical treatment; rod fractures.

ПЕРЕЛОМЫ СТЕРЖНЕЙ В ХИРУРГИИ ДЕФОРМАЦИЙ ПОЗВОНОЧНИКА (АНАЛИЗ МАТЕРИАЛА КЛИНИКИ И СИСТЕМАТИЧЕСКИЙ ОБЗОР ЛИТЕРАТУРЫ)

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Обоснование. Переломы стержней — одно из специфических осложнений в хирургии деформаций позвоночника. Количество публикаций на эту тему невелико, а выводы авторов часто противоречивы.
Цель — анализ проблемы переломов стержней эндокорректора при деформациях позвоночника различной этиологии с учетом частоты и факторов риска развития этого осложнения.
Материалы и методы. В исследование были включены 3833 пациента, оперированных в период с 1996 по 2018 г. Критерии включения — возраст старше 10 лет, отсутствие операций на позвоночнике в анамнезе.
Результаты. Переломы стержней металлоимплантатов выявлены у 85 больных из 3833 (2,2 %). Существует значимая разница между группами идиопатических и врожденных сколиозов. Перелом стержня у 62 больных из 85 послужил поводом для повторного вмешательства — восстановление целостности стержня коннектором либо полная его замена. Увеличение индекса массы тела на 1 повышает шансы перелома в 1,07 раза (p = 0,019), увеличение возраста на один год повышает шансы перелома в 1,03 раза (p = 0,039). Статистически значимой связи вентрального этапа оперативного лечения (дискэктомия и межтеловой спондилодез аутокостью) с переломом не обнаружено (p = 0,403). Статистически значимым предиктором в группе пациентов до 20 лет является возраст больше 15 лет (p = 0,048). Для индекса массы тела статистически значимого порога относительно шансов перелома в группе пациентов до 20 лет не выявлено. Гибридная система фиксации дает значимо меньший процент осложнений, чем крючковая.
Проведен систематический обзор литературных источников по обсуждаемой теме в международных базах данных Scopus, Medline, GoogleScholar, а также поиск публикаций по пристатейным спискам литературы.
Заключение. Переломы стержней в хирургии деформаций позвоночника различной этиологии представляют собой одно из типичных осложнений. Частота переломов стержней в больших группах исследования невелика. Риск развития этого осложнения повышается с увеличением индекса массы тела и возраста пациента, хотя для индекса массы тела статистически значимого порога относительно шансов перелома в группе пациентов до 20 лет не установлено. Современные педикулярные системы крепления эндокорректора к позвоночным структурам позволяют значительно снизить риск перелома стержней в послеоперационном периоде.

Ключевые слова: деформации позвоночника; хирургическое лечение; переломы стержней.

Surgery is impossible without complications, and surgical correction of spinal deformities is no exception. There are several specific vertebrological complications directly related to the metal implant (implant-related complications [IRC]), namely, fractures of the rods and screws, spontaneous dismantling of the hardware, displacement of its elements, damage to supporting bone structures, and extension of the metal implant under the skin. A huge number of studies focus on the complications of vertebral surgery, but the IRCs are not reflected enough in them and, which is especially noticeable, undifferentiated, as a kind of homogeneous amorphous group; the constituent elements of which are not fundamentally different from each other [1–4].

Several works have been focused on fractures of the endocorrector rods as an independent problem (and we believe that this is the case) [5–10]; however, an analysis of their content does not enable to conclude the frequency of development of this complication, since the groups of patients under consideration are relatively small (a maximum of a few hundreds), and the results obtained are very variable (from 0% to 27%). The authors of these publications analyze risk factors for rod fractures; however, their data are sometimes contradictory, and the potential number of causes of rod fractures is large. We consider it important to note that in Russian literature, we were not able to find publications on the issue under discussion.

Not all patients included in the study were younger than 20 years old; however, children and adolescents accounted for almost 70% of the total number examined, and surgical treatment of patients of various age categories is based on the same principles.

This study aimed to analyze the current state of the problem of fractures of endocorrector rods during spinal deformities of various etiologies, taking into account the frequency and risk factors for the development of this complication.

Material and methods

The study included 3,833 patients who underwent surgery from 1996 to 2018 for spinal deformities of various etiologies over the age of 10 years and who had not undergone spinal surgery before admission to the clinic, namely, 2,670 (69.63%) patients at the age of 11–20 years, 852 (22.23%) patients aged 21–31 years, 252 (6.59%) patients aged 31–40 years, and 59 (1.54%) patients aged 41–50 years. Patients under 10 years old were treated in our clinic using multistep methods of "growing rods" (TGR, VEPTR). The complications that arose during this (fractures of the rods, displacement of the grips, etc.) were stopped during the next stage distraction. In rod fractures in adolescents and adults who underwent a single dorsal intervention using tools of the third generation, a different therapeutic approach was used, and therefore, they were allocated into a separate group. The upper age limit for such patients was 46 years. Exclusion criteria were ventral spinal instrumentation and previously performed surgeries on the spine. Modern spinal dorsal instruments were used as an endocorrector, which is made of titanium alloys in the vast majority of cases. In the preoperative and postoperative period, spondylograms were studied in a frontal and lateral projection in a standing position.

Statistical methods. Empirical data distributions were checked for compliance with the normal distribution according to the Shapiro-Wilk criterion. All data were abnormally distributed ($p < 0.001$). Estimates were presented as medians and quartiles I and III.

The hypothesis on the equality of the numerical characteristics of the sample distributions in the compared groups was checked using the nonparametric Mann–Whitney U-test, and the displacement distributions were calculated with the construction of a 95% confidence interval.

Predictors of anterior surgery were identified by constructing logistic regression models. Individual predictors of the ventral stage of intervention were determined by constructing one-factor models. Before constructing multivariate models, collinear covariants were calculated using the Pearson correlation coefficient. The optimal multivariate logistic regression models were constructed from the original multivariate models (including covariants with an achieved significance level $p < 0.300$) and univariate models for additional control using the forward and reverse steps of the Akaike information criterion. The models obtained by the forward and reverse steps coincided.

Statistical hypotheses were tested at a critical significance level $p = 0.05$, that is, the difference was considered statistically significant if $p < 0.05$. The lower limit of the criterion power was taken equal to 80%.

All statistical calculations were performed in the Rstudio program (version 1.2.5001 — © 2009–2019, USA) in the R language (R Core Team (2015). R: A language and environment for statistical computing. R Foundation for statistical computing, Австрия. URL: https://www.R-project.org/).

Results

In total, fractures of metal implant rods were detected in 85 of 3,833 patients, which is 2.2%. Fractures were noted 64 times (2.1%) in 3,068 patients with idiopathic scoliosis (IS). In 374 patients with congenital deformities and 391 patients with deformities of a different etiology (neurofibromatosis in four cases, Scheuermann's disease in one case, and neuromuscular scoliosis in one case), fractures were noted 15 (4.0%) and 6 (1.5%) times, respectively. Statistical processing shows that without taking into account the error of multiple comparisons, there is a significant difference between the groups of idiopathic and congenital scoliosis (odds ratio [OR] 0.51 [0.28; 0.97]; $p = 0.027$) and between congenital scoliosis and other deformities (OR 2.68 [0.97; 8.52]; $p = 0.045$). Taking into account the correction for the error of

Table 1

The frequency of rod fractures and the spinal deformity etiology

Etiological forms	Number of patients	Number of fractures *n*, % [95% CI]	Bilateral Fisher test: OR [95% CI] (*p*, adjusted *p*)
1 — Idiopathic	3068	64, 2.1% [1.6; 2.7]	**1–2**: 0.51 [0.28; 0.97] (0.027*; 0.068) **1–3**: 1.37 [0.59; 3.89] (0.570; 0.570) **2–3**: 2.68 [0.97; 8.52] (0.045*; 0.068)
2 — Congenital	374	15, 4.0% [2.4; 6.5]	
3 — Other deformities	391	6, 1.5% [0.7; 3.3]	

Note. To take into account the effect of multiple comparisons, the corrected p was calculated by the Benjamini–Hochberg method. OR, odds ratio; CI, confidence interval.

Table 2

The frequency of fractures of the rods and the type of the endocorrector fixation

Type of fixation	Number of patients	Number of fractures *n*, % [95% CI]	Bilateral Fisher test OR [95% CI] (*p*, adjusted *p*)
1 — Hook	1725	60, 3.5% [2.7; 4.5]	**1–2:** 1.82 [1.11; 3.07] (0.013*; 0.013*) **1–3:** 20.5 [3.5; 821] (<0.001*; <0.001*) **2–3:** 11.3 [1.8; 463] (0.002*; 0.003*)
2 — Hybrid	1236	24, 1.9% [1.3; 2.9]	
3 — Pedicular	570	1, 0.2% [0.0; 0.9]	

Note. To take into account the effect of multiple comparisons, the corrected *p* was calculated by the Benjamini–Hochberg method. OR, odds ratio; CI, confidence interval.

Table 3

General characteristics of the studied patients ($N = 3529$)

Variables	Values
Body mass index Me [IQR] M ± CD	 19.2 [17.4; 21.2] 19.59 ± 3.35
Age years Me [IQR] M ± CD	 16.4 [14.3; 20.3] 18.43 ± 6.45
Diagnosis, *n* (%): Scheuermann's disease Syndromic scoliosis Idiopathic scoliosis Congenital scoliosis	 16 (0.5%) 352 (10%) 2820 (79.9%) 340 (9.6%)
Ventral surgery *n*, % [95% CI]	 1039, 29% [28; 31]
Rod fracture *n*, % [95% CI]	 83, 2% [2; 3]

Note. CI, confidence interval; Me, median; IQR, interquartile range; M ± CD, arithmetic mean value ± standard deviation.

Table 4

Univariate logistic regressions of rod fracture in a group of patients under the age of 20 years

Variables	OR [95% CI]	*p*-level
Body mass index	1.07 [0.98; 1.16]	0.126
Age	1.12 [0.99; 1.28]	0.066
Front surgery	0.82 [0.43; 1.49]	0.533
Age > 15 years	1.82 [1.02; 3.38]	0.048*

Table 5

Univariate logistic regressions of rod fracture in a group of patients over the age of 20 years

Variables	OR [95% CI]	*p*-level
Body mass index	1.05 [0.95; 1.15]	0.326
Age	0.98 [0.92; 1.04]	0.536
Front surgery	0.86 [0.34; 1.92]	0.723

Note. OR, odds ratio; CI, confidence interval.

multiple comparisons, no statistically significant difference in the groups was found (Table 1).

A sufficiently large number of rod fractures in patients with congenital spinal deformities prompted us to consider separately this group of patients. The calculations showed that a statistically significant risk factor was the initial value of the kyphotic component of congenital spinal deformity of more than 100°. In this case, the rod fracture OR increases by 5.44 [1.72; 16.38] times ($p = 0.003$).

Of the 85 patients, 60 were operated using only hook fixation and 24 using a hybrid fixation (hooks and pedicular screws), and one case used all screws. These differences are statistically significant (Table 2). The total number of patients in Table 2 (3,531) is less than the above number of patients examined (3,833), which is associated with errors when entering information into the electronic database; however, the cases not taken into account here are not related with fractures of the rods.

Fracture of one rod was detected in 51 patients, and fracture of two rods was noted in 34 patients. The level of damage to the integrity of the rod varied significantly, namely, Th_6–Th_{10} in 16 patients, Th_{11}–L_4 in 65 patients, and L_5–S_1 in 1 patient. The number of devices for transverse traction (DTT) used during the installation of endocorrector was different. Each of 4 patients had one device, 78 patients had two, 2 patients had three; DTT was not used in one case. We draw attention to this because, over the course of many years of work, we had the impression that the location of the fractures of the rods depends on the location of the DTTs, which were conventionally located at the ends of the structure. Measurement of the distance from DTT to the site of the fracture of the rod in 63 patients showed that in 22 cases, it does not exceed 2.5 cm, and in 37 cases, it varies from 3 to 17 cm; the fracture was noted in the absence of lateral traction in one patient.

Fracture of the rod in 62 of 85 patients necessitated repeated intervention, including the restoration of the integrity of the rod with a connector or its complete replacement. Indications for this surgery were the loss of the achieved correction and pain. In 18 out of these 62 patients, a relapse of the fracture was noted, which required two to four repeated surgeries. The exact timing of the fracture of the rod in most cases could not be identified, although some patients indicated an injury that could cause the development of complications. On average, a repeated intervention was performed 38.4 months (4–126 months) after corrective surgery.

An attempt was made to establish a relationship between the frequency of rod fractures and factors such as body mass index (BMI), patients' age, and ventral spinal fusion surgery (Table 3). By constructing one-factor models of logistic regression, the following was revealed:

- an increase in BMI by 1 increases the risk of a fracture by 1.07 [1.01; 1.14] times ($p = 0.019$);
- an increase in age by 1 year increases the risk of a fracture by 1.03 [1; 1.06] times ($p = 0.039$);
- there is no statistically significant relationship between the ventral stage of surgical treatment (discectomy and vertebral fusion with autobone) and a fracture ($p = 0.403$).

Separately, risk factors for rod fracture were analyzed for age groups up to 20 years and older than 20 years (Tables 4 and 5).

A statistically significant predictor in the group of up to 20 years was the age of more than 15 years; in these patients, the ratio of the chances of a rod fracture increased by 1.82 [1.02; 3.38] times ($p = 0.048$). For BMI, there was no statistically significant threshold relative to the chances of a fracture in the group under 20 years of age.

There were no statistically significant predictors in the group of over 20 years.

Literature review

To collect information on the topic under discussion, we used the international databases Scopus, Medline, and Google Scholar. An additional search was also performed for publications on references in the articles.

The problem of fractures of the endocorrector rods has existed since Harrington, but orthopedic literature contains worryingly little information on this issue (Table 6). This topic is multi-aspectual, which determines the nature of its discussion.

Frequency of complications and repeated interventions. Coe et al. analyzed 6,334 cases of surgical treatment of IS in adolescents (ISA) [11]. Complications were identified in 363 cases (5.7%), and the frequency of IRC was 0.25%. According to Richards et al. [12], the number of repeated surgeries was 172 in 135 patients (12.9%) of 1,046 patients with IS. According to Carreon et al. [2], out of 702 patients with ISA, three patients reported late failure without decoding, which required repeated surgery. Weiss and Goodall [13] presented a systematic review of 287 works. They reported that the frequency of complications in scoliosis surgery varies from 0% to 89%. In particular, the postoperative progression of deformity may be due to a fracture of the rod. According to Mok et al. [14], repeated surgeries with spinal deformities in adults were noted in 25.8% of 89 patients. Fu et al. [15] presented a review of complications, which included 23,918 patients operated on for spinal deformities of various etiologies; the average age was 13 years. The total number of complications was 2,020 (8.5%), including 1.4% of IRC. With idiopathic scoliosis, the frequency of repeated surgeries was 7.5% (34 out of 452), whereas a fracture of the rod occurred in only one case [16]. According to Jain et al. [3], in 1,002 pediatric patients operated for spinal deformities, rehospitalization was noted in 8% of cases, and repeated surgery was performed in 3.8% cases. The authors did not provide information on rod fractures. Ahmed et al. [1] analyzed the results of the surgical treatment of 1,435 patients with ISA, aged 10 to 22 years. Within 5 years after the intervention, repeated surgeries were performed in 75 cases (5.2%), while in 22 cases, it was conducted within 3 months after the surgery, in 10 cases for up to 1 year, in 12 cases for up to 2 years, in 20 cases for up to 5 years, and in 10 cases, it was performed 5 years after the surgery. The authors cite literature data, according to which, implant failure occurs with a frequency of 0.7% to 1.4% [16]. The reasons for repeated surgery include loosening of the pedicular screw (3), displacement of the hook (2), unscrewing of the screw (2), fractures of the rod, and false joint of the block (9).

De la Garza Ramos et al. analyzed 74,525 cases of surgical treatment of the spine in children, and

Table 6

Literature data on the problem of rod fractures in surgery for spinal deformities

Authors	Year	Number of patients	Age	Etiology of deformity	Surgery type	Complications	Repeated surgery	IRC	Rod fractures
Coe et al.	2006	4,369	Adolescents	IS	Dorsal instrumentation	221 (5.1%)	–	28 (0.64%)	–
Richards et al.	2006	1,046	14.5 years	IS	Dorsal and ventral instrumentation	–	172 surgeries in 135 patients (12.9%)	15 (1.4%)	–
Yang et al.	2006	35	Adults	Degenerative scoliosis	PSO	15 (42.8%)	–	6 (22%)	3 (11%)
Carreon et al.	2007	702	14.2	ISA	Dorsal instrumentation	108 (15.4%)	5 (0.71%)	3 (0.43%)	–
Mok et al.	2009	89	Adults	Degenerative scoliosis	Dorsal instrumentation	–	25.8%	4	0
Fu et al.	2011	23,918	13	Primarily ISA	–	2020 (8.5%)	–	371 (1.6%)	–
Ramo, Richards	2012	452	14.6	Primarily ISA	Dorsal instrumentation	–	34 (7.5%)	11 (2.4%)	0
Smith et al.	2012	442	Adults	Degenerative scoliosis	Dorsal instrumentation and PSO	–	–	–	30 (6.8%), in PSO — 15.8%
Akazawa et al.	2013	155	19	ISA	Dorsal instrumentation	–	–	–	8 (5.2%)
Smith et al.	2014	200	Adults	Degenerative scoliosis	Dorsal instrumentation and PSO	–	–	–	18 (9%), after PSO — 22%, without PSO — 4.7%
Jain et al.	2015	1,002	10–18 years	Primarily ISA	Dorsal instrumentation	–	3.8%	9 (0.9%)	–
Smith et al.	2016	291	Adults	–	Dorsal instrumentation, 64% — vertebral column resection	469 in 203 (69.8%) patients	–	–	40 (13.7%)
Ahmed et al.	2016	1,435	15.2	ISA	–	–	75 (5.2%)	–	9
De la Garza Ramos et al.	2017	74,525	–	–	–	8.6%, in the revision group — 16.7%	2052 (2.7%)	0.4%, in the revision group — 5.3%	–
Kavadi et al.	2017	26	19 adults and 7 children	Scoliosis of various etiology	PSO and VCR	–	–	–	7 (27%)
Thamrong et al.	2018	526	Adults	–	–	–	–	–	97 (18–4%)

Note. IS, idiopathic scoliosis; ISA, idiopathic scoliosis of adolescents; PSO, pedicle subtraction osteotomy; IRC, implant-related complications; VCR, vertebral column resection.

2,052 surgeries were revision (2.7%). In general, the number of complications in the primary and revision groups was 8.6% and 16.7%, respectively. Complications associated with implants in the group of primary surgeries were recorded in 0.4% of cases and 5.3% in the revision group [17].

The frequency of fracture rods. In a review by Yang et al., which included 35 patients with pedicle subtraction osteotomy (PSO) in the thoracic and lumbar spine, rod fracture was found in 11% of patients (three cases), first on one side and then on the other. All fractures occurred in the lumbar region since the load there is greater, and it has no stabilizing effect of the chest. For the manufacture of rods, titanium was used, which does not impair the quality of the magnetic resonance imaging (MRI) image but is fragile and prone to microfractures. In all cases, repeated surgeries were required [18]. A multicenter study of Lykissas et al. showed that rod fractures reach 6.8% (30 of 442) in scoliosis surgery with titanium alloys in 8.6%, steel in 7.4%, and cobalt and chromium in 2.4% [19]. Akazawa et al. considered the results of the treatment of 155 patients with deformities of various etiologies (the majority had ISA). The average age of the patients was 19 years, and the average follow-up period was 46 months. Initially, the Cobb angle of the main arc was 61°; the average length of the instrumentation zone was 10 segments. Rod fracture was detected in eight patients (5.2%). Fractures occurred, on average, 18 months after the intervention. The level of fracture varied from the thoracolumbar to the lumbosacral spine, and a fracture of the rod was noted close to the lower instrumented vertebra in six patients [5].

Dailey et al. [6] described a case of a fracture of two rods in a 24-year-old woman with the complete release of one fragment from the screw heads and migration to the gluteal region, from where it was removed. Kavadi et al. analyzed the frequency of rod fractures in 26 patients after the surgery of a three-column vertebral column resection (VCR and PSO). In seven cases (27%), rod fractures were recorded, and more often, they were fractures of both rods (five patients). In 71% of cases, pain and violation of the sagittal balance occurred; in the remaining cases, no symptoms were detected. The diagnosis of fracture was established approximately 1 year after the surgery, six out of seven at the level of a vertebral column resection. The average number of blocked segments was 11.2. Titanium rods were used (all fractures), but in two children, they were steel. The fracture duration was 6–12 months [7].

Thamrong et al. analyzed the incidence of rod fractures in adult patients after surgery of the dorsal fusion lasting to the sacrum in 526 patients aged 18 to 80 years (average 56.8); the average follow-up was 57 months [10]. Fractures of the rods were detected in 97 cases (18.4%), whereas one rod was broken in 61 patients and two rods in 36 patients. The rods made of stainless steel turned out to be more reliable. The authors define a fracture of the rod as damage to its integrity, at least in one place after the initial intervention. A fracture of the rod was recorded on average 39.6 months after the surgery, namely, during up to 3 years in 51 patients, from 3 to 5 years in 23, from 5 to 10 years in 22, and over 10 years in 1. In 36 patients with a unilateral fracture, 79 points of integrity damage were noted, while in one patient, the rod was broken in four places. Most often, the rods broke at the level of segments L_5–S_1 and L_3–L_4. In the latest examination, 57 patients showed no pain or loss of correction, and another 40 patients underwent revision intervention due to pain, loss of correction, and implant protrusion. More often, patients with a fracture of both rods were operated, while the time interval between the diagnosis of the fracture and the revision surgery was 3 months.

Series of works by Smith et al. focus on rod fractures after dorsal interventions for spinal deformities in adult patients; these were multicenter studies conducted by groups of authors with slightly different compositions [8, 9, 20]. A significant proportion of patients in all three groups were operated using PSO. In the work of 2012, 442 patients were reported, among which a fracture of the rods was noted in 30 patients (6.8%). Rods made of cobalt-chrome alloy broke significantly less frequently than titanium ones. Pain was the main symptom in 97% of cases of rod fracture. For 22 out of 30 patients, indicators of growth and weight before surgery were presented; the BMI in this group was 30, which corresponded to the category of obesity. Fracture of one rod was detected in 21 patients, which of two rods was in nine cases. Most of the rods broke in the lumbar and thoracolumbar spine. In 22 cases, DTT was used (one or more), while in only three cases, the rod was broken at the level of transverse thrust.

PSO surgery was complicated by rod fracture in 15.8% (18 of 114) cases. The average time interval between the surgery and fractures of the rods was 15.7 months (2–73 months). Revision surgeries were performed in 26 out of 30 patients; the broken rods were removed in no case, and reconstruction was performed with the restoration of the structural support ability. The authors were able to establish a connection between fractures of the rods with the initial disturbances in the sagittal balance.

In a 2014 publication, Smith et al. analyzed a group of 200 patients, and rod fractures were detected in 18 (9%) of them and in 22% of cases after PSO [9]. The third of the works of the group of Smith et al. focused on the complications of corrective interventions on the spine in adults, and the rate of rod fractures was found to be 13.7% (40 cases per 291 patients) [20].

Rod fracture risk factors have been studied by several authors. Wattenbarger et al. reported that when using the two-rod design, rod fractures were not present in all 103 patients, and in the group of patients operated on using the single-rod design, rod fractures were noted nine times (21%), six cases of which were accompanied by pain and five cases required repeated surgery [21]. Akazawa et al. considered bed rest as a risk factor for rod fracture after surgery for spinal deformities, as well as preoperative kyphosis, small rod diameter, multiple interventions, and the use of iliac screws [5]. The risk factors did not include gender, obesity, the magnitude of scoliotic deformity, and the metal of the rod. According to Soroceanu et al., the absolute weight of the patient is more important in the development of biomechanical complications than BMI [22]. As risk factors, numerous concomitant diseases and large deformation in the sagittal plane were indicated. In a 2014 publication, Smith et al. noted the risk factors, such as the older age of the patients, obesity, history of vertebral surgeries, sagittal imbalance, and cobalt-chromium alloy rods [9]. Kavadi et al., who studied the results of radical surgeries (PSO and VCR), indicated the main causes, such as increased tension on the rods and the relative deficiency of bone tissue at the site of laminectomy [7]. Thamrong et al., who analyzed the results of spinal fusion with sacral capture in adult patients, considered sagittal imbalance, preoperative lumbar kyphosis, and the length of the formed block as risk factors [10].

According to Yoshihara et al., there are three types of alloys from which the rods are made, namely, iron–chromium–nickel (stainless steel), titanium and its alloys, and cobalt-based and chromium-based alloys [23]. Titanium is characterized by biocompatibility and corrosion resistance, and it does not affect the quality of MRI images. The stability of the rod fixation depends on such biomechanical properties of the alloy as yield limit, rigidity, and fatigue strength. The ideal numbers for these parameters are unknown. Also, the material, length, diameter, shape, and number of rods are important. So, Albers et al. and Friska et al. showed that the two-rod design is significantly stronger than the single-rod when using both dorsal and ventral instruments in IS surgery [24, 25]. Intraoperative bending can lead to surface microdefects. Surface microdefects can also occur at the point of contact of the rod with a hook or a screw, which causes fatigue instability of the rod (notch sensitivity). As it is known, the stress concentration in the form of scratches and grooves affects significantly the metal fatigue, because fractures almost always occur at the point of the initial increase in stress.

Rod Bends and Fractures. Lindsey et al. conducted a mechanical study of rods (metal fatigue) of titanium and stainless steel. It turned out that the rods preliminarily bent with the use of a French bender, regardless of the type of metal, broke in one of the bending places [26]. Straight rods, both titanium and steel, broke at the point of attachment of the screw head to the rod. Kokabu et al. revealed that intraoperative contouring of the rods to optimize the anatomical relationships in the thoracic spine reduces the risk of fracture [27]. They studied 46 patients with ISA and found that improper bending leads to the concentration of loads at certain points, which can cause fatigue fracture of the rod.

Almost no one disputed the use of transverse rods in hook systems; however, the ubiquitous transition to pedicular screws changed the situation significantly. Garg et al., having examined two groups of patients (377 patients operated using DTT and 123 without DTT), concluded that lateral traction does not provide any advantages with the all screw technique in ISA patients [28]. Moreover, DTT can be the cause of pseudoarthrosis due to impaired formation of a bone block in the midline. In a study in adults, it turned out that false joints in 69% of cases were formed precisely at the DTT location [29]. A similar conclusion was made by Dhawale et al., who analyzed the results of the surgical treatment of 125 ISA patients (75 patients with DTT and 50 without them) [30].

Another rarely discussed aspect is the *removal of the endocorrector*. The creators of the Cotrel-Dubousset instrumentation recommend not to do this unless necessary, since the removal of a massive metal implant, which is a bone-sealed artifactual block, represents a significant traumatic intervention [31]. Teles et al. consider that the endocorrector should be removed only according to very justified indications, since, according to their data, the implant protects the spinal column from inadequate loads (stress-shielding effect). Otherwise, the development of mechanical complications (fracture of the bone block) in the absence of traumatic effects is possible [32].

In general, despite a very limited number of studies, the problem associated with implants is quite serious. Renshaw wrote, “It can be expected that if the patient lives long enough, the likelihood of a rod fracture becomes real” [33]. Hawes suggested warning the patients and their families that the surgery may not be the last [34].

Discussion

Over the years, the experience of unfortunate and inevitable complications in vertebrological practice has been accumulated. Moreover, in surgical vertebrology, several complications can be considered specific, namely, complications associated with implants and suppuration (early and late) and the development or aggravation of neurological symptoms. A huge amount of research has been devoted to the development and treatment of these complications, although the IRC problem in this regard is considered to be far from being resolved. Based on the literature on fractures of the endocorrector rods in surgery for spinal deformities, we can talk about a significant heterogeneity of quantitative indicators of the frequency of development of complications and the ambiguity of the very assessment of the problem.

The clinical material analyzed by us is the most extensive of the published as it included 3,833 patients, with 85 fractures of the rods detected in them. The clinic provides surgical treatment for patients with spinal deformities of various etiologies, and not only children and adolescents. At the same time, patients operated under the age of 10 years were excluded from the study, since the surgical approach applied to these pediatric patients is fundamentally different from patients of other age groups. We were interested in the frequency and risk factors for complications. The frequency (2.2%) turned out to be relatively low, especially taking into account some literature data. The etiology of scoliosis is not a risk factor, but with congenital deformities, fractures of the rods have been noted more often as a percentage, probably due to the specifics of this pathology. One of the aspects is the presence in many cases of the kyphotic component of the deformation. It turned out that congenital kyphosis is a risk factor only when it reaches 100°. As a result of stage I of a two-level intervention (discectomy), the support ability of the ventral column of the spine can theoretically decrease, which is not a risk factor for the development of complications. At the same time, BMI, age (including in the age groups under and over 20 years, considered separately), and especially the type of fixation of the endocorrector can affect the number of complications, in particular, transpedicular fixation is much less often accompanied by a fracture of the rod than a hybrid or hook one. The risk of damage to the rods increases between the ages of 15 and 20 years. The assumption that the location of the rod fracture is related to the location of the DTT has not been convincingly confirmed. Our multivariate analysis, of course, cannot be considered final, because the number of factors studied can be arbitrarily large.

The main limitation of the information content of the study is the heterogeneity of the group of patients (although the vast majority of them are patients with idiopathic scoliosis).

Conclusion

Fractures of the rods in the surgery of spinal deformities of various etiologies represent one of the typical complications. Its frequency in large research groups is low. The risk of occurrence of this complication increases with an increase in patient’s BMI and age, although no statistically significant threshold was found for BMI in relation to the chances of a fracture in the group under 20 years of age. Modern pedicular systems of fastening the endocorrector to the vertebral structures, in turn, can reduce significantly the risk of fracture of the rods in the postoperative period.

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All patients coming to the clinic of the I.L. Tsivyan Novosibirsk Research Institute of Traumatology and Orthopedics for surgical treatment sign a consent to processing and publication of personal data.

Contribution of authors

M.V. Mikhailovskiy developed study methodology, performed data analysis, wrote all sections of the article.

A.S. Vasyura was involved in search and analysis of literature data, processing of the clinic material.

V.L. Lukinov performed statistical data processing, analysis of the results obtained, and their discussion with co-authors.

All authors made a significant contribution to the research and preparation of the article, read and approved the final version before its publication.

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