SOME EPIDEMIOLOGICAL INDICATORS AND RESULTS OF SURGICAL TREATMENT OF CHILDREN WITH UNSTABLE AND COMPLICATED SPINE INJURIES USING DIFFERENT MODELS OF MEDICAL CARE BASED ON THE EXAMPLE OF A CONSTITUENT ENTITY OF THE RUSSIAN FEDERATION

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Objective. To analyze incidence rates and prevalence of unstable and complicated spinal injuries in pediatric patients and the results of their surgical treatment using different models of medical care.

Material and Methods. A total of 117 patients under 18 years of age with high-energy traumatic injuries of the spinal column were treated in the period from 2010 to 2023. The entire 14-year period was divided into 2 stages, taking into account the model of care provided to these patients. Stage 1 (2010–2016) included supervision of patients with spinal injuries by pediatric traumatologists-orthopedists and neurosurgeons with a decision on the advisability and timing of specialized treatment with involvement of a spine surgeon from the adult regional hospital to perform the operation. Stage 2 (2017–2023) included total supervision of patients with spinal injuries by specialists from the adult vertebrology department with a decision on the advisability, timing and scope of surgical intervention that would be performed in an adult hospital. The analysis included the number of patients, their epidemiological characteristics, types and location of spinal injury, timing of surgical care, as well as the tactics of surgical treatment taking into account two time stages of care.

Results. In 2010–2016, 22 children and adolescents with spinal injuries were operated on, of which 15 (68.2 %) suffered from neurological deficit. In 2017–2023, 95 victims underwent surgical treatment, of which 28 (29.4 %) had neurological deficit. After changing the concept of determining the grounds for surgical treatment and routing of victims (2017), a disproportionate increase in their total number (22 versus 95) and the number of victims with complicated spinal fractures (15 versus 28) was noted. In total, the number of children and adolescents hospitalized for surgical treatment in the periods under review increased more than 4-fold (by 332.0 %), and the number of complicated spinal injuries increased less than 2-fold (86.7 %).

Conclusion. Centralization of specialized medical care for children with spinal injuries in a functioning spinal surgery department of an adult hospital with the appropriate material and technical base, including instrumentation for children of all age groups, and the routine use of various surgical techniques ensures a unified approach to the principles of diagnosis and treatment of this category of patients with the achievement of good results.

Key Words: pediatric spinal injury; epidemiology of spinal trauma; organization of spinal care; constituent entity of the Russian Federation.

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Traumatic spinal cord injuries are a challenging medical and social issue. They are typical for both adults and children. The issues of diagnosis and treatment of adult patients with unstable and complicated spinal injuries are widely and in detail covered in the literature. However, there are few summaries, including meta-analyses, on the issue of spinal fractures in children. This is explained by the fact that, firstly, this pathology is less common in children than in adults (1–3 % of the total number of musculoskeletal injuries on mean), and secondly, children have a principally different pattern of spinal fracture distribution, with the number of compression fractures being up to 80 % [1].

Difficulties in understanding the incidence of spinal cord injuries in children are associated with different accounting units for the occurrence of this pathology. For example, Mendoza-Lattes et al. [2] indicate that the incidence of spinal injuries is 93–107 per 1,000,000 total population and tends to increase, and S.V. Vissarionov et al. [3] provide figures on the prevalence of spinal cord injuries per 1,000,000 pediatric population. Considering this inconformity, it is challenging to interpret the available literature data.

The data on the number of spinal cord injuries in children and the number of surgeries performed per the total number of pediatric neurosurgeons and traumatologists-orthopedists demonstrate that there is little experience in diagnosis (especially of borderline cases) and even less experience in surgical treatment in the general population of these specialists. This situation is a primary cause of misinterpreted spinal column fractures (especially unstable injuries). Conversely, this results in an unreasonable approach to the treatment of this category of patients and technical errors during surgery. This forms the cohort of patients requiring surgical treatment either in large federal specialized children's centers or in adult hospitals after some time, when patients move into the "adult" category.

The objective is to analyze incidence rates and prevalence of unstable and complicated spinal injuries in pediatric patients and the results of their surgical treatment using different models of medical care.

Material and Methods

Study design: a retrospective cohort study. The study is based on the analysis of the surgical treatment outcomes of 117 patients (under 18 years old) from 2010 to 2023.

Inclusion criteria:

1) high-energy traumatic injuries of the spinal column at the cervical, thoracic, and lumbar levels;

2) burst or comminuted fracture according to the AO Spine classification (A2–4, B1–3, C).

Exclusion criteria:

1) compression fracture of one or more vertebrae with local deformity not exceeding 15°;

2) sacral and coccyx fractures;

3) patients who were not operated on in the acute period of traumatic injuries because of various reasons.

The entire analyzed 14-year period of care for pediatric patients with spinal cord injuries was subdivided into 2 stages:

Stage 1 (2010–2016): supervision of patients with spinal cord injuries by traumatologists-orthopedists and neurosurgeons of the pediatric service with decision on the advisability and timing of specialized treatment, with the involvement of a spine surgeon from an adult regional hospital to perform surgery.

Stage 2 (2017–2023): total supervision of patients with spinal cord injuries by specialists of an adult vertebrology department with decision on the advisability, timing, and scope of surgical intervention that was performed at an adult hospital.

At stage 1, the routing of patients was performed according to the chart shown in Fig. 1.

The presented chart is rather complicated in terms of the timeframe for providing specialized surgical care to the injured because of additional consultations and approvals for patient transfer. Furthermore, when analyzing patient routing in the long-term follow-up period, an underestimation of the severity of spinal column injuries was noted at the stage of consultations with pediatric specialists in different hospitals. Therefore, some patients with signs of unstable injuries without neurologic deficit did not receive specialized surgical care. They consulted specialists in a long-time period after the injury with complaints of pain syndrome, pronounced orthopedic disorders (post-traumatic spinal deformity), and signs of vertebromedullary conflict (neurological disorders of varying severity). Therefore, a different patient routing plan was developed (Fig. 2) that provides an opportunity to optimize the diagnostic process of identifying patients with unstable and complicated spinal cord injuries and to perform a rational stage of patient admission to a specialized hospital for surgery, as well as to provide care based on the real situation and features existing, excluding additional negotiation processes and unreasonable transfers between hospitals.

Using the two-time stages of care, the number of injured patients, their epidemiological features, types and sites of spinal injury, timing of specialized care by a spine specialist, and surgical strategies were analyzed.

Statistical processing of the outcomes. The obtained clinical outcomes were processed in the IBM SPSS 16.0 software system while considering the features of the cohort using descriptive statistics methods only.

Results

There were 77 (65.8 %) boys and 40 (34.2 %) girls among the injured patients. The most frequent spinal injuries were diagnosed at the age of 14–17 years and accounted for 95 (81.2 %) patients. The causes of spinal cord injuries were traffic accidents – 61 (52.1 %), falls from a height – 26 (22.2 %), sports-related injury – 19 (16.2 %), and home accidents – 11 (9.4 %). The ratio of boys to girls was 1.4:1.0 in 2010-2016, while in 2017–2023 the proportion of boys increased to a ratio of 2.1 : 1.0, which corresponds to the more pronounced

physiological activity and mental characteristics in boys (Table 1).

On admission to the hospital, 4 (9.3 %) patients were found to have neurologic deficit type A according to the Frankel scale, 3 (6.9 %) patients with type B, 11 (25.7 %) patients with type C, and 25 (58.1 %) patients with type D.

Surgical treatment was performed according to the generally accepted principles of specialized medical care for patients with spinal cord injuries [4, 5].

The extent of surgical care in cervical spine injuries (n = 40) depended on the anatomical area of injury and the nature of injury. In 5 (12.5 %) cases, there was traumatic injury to the craniovertebral junction, and dorsal stabilization with mini polyaxial screws was preferable. In surgical treatment of subaxial cervical fracture, we used a conventional anterior cervical approach with discectomy or corpectomy for decompression and restoration of anatomical relationships in the area of injury, as well as one-stage replacement of the defect with a graft and stabilization with a cervical plate. Such surgeries were performed on 27 (67.5 %) patients. In the most complicated cases associated with gross injuries and pronounced dislocations, a combined anteroposterior approach was used in 8 (20 %) patients.

Transpedicular stabilization of the spinal motion segments was performed in thoracic and lumbar fractures (n = 77) with 4–6–8–10 screws depending on the number of broken vertebrae, type and nature of the injury. Minimally invasive percutaneous fixation was used in 48 (62.3 %) cases, and an open approach was used in 29 (24.8 %). Conventional open surgeries were used in young and middle-aged children because of the small size of the vertebrae, the need to place mini polyaxial screws (there are no cannulated screws of this type), and to form a posterior bone block along the instrumentation. Twenty patients (26.0 %) underwent surgical treatment with the addition of laminectomy in the thoracolumbar spine. Fifty seven (74.0 %) patients underwent surgery without laminectomy.

Eighty (68.4 %) patients had isolated spinal injuries, 37 (31.6 %) patients had multiple vertebral injuries, and 41 (35.0 %) patients had combined injuries. In isolated, multiple, as well as mild and moderate combined injuries, as a rule, the full extent of surgical care was performed, and in severe combined injuries, the treatment was performed in stages using the Damage Control Principle.

After the change in the concept of determining the grounds for surgical treatment and routing of patients (2017), there was a disproportionate increase in the total number of patients (22 vs. 95) and the number of patients with complicated spinal fractures (15 vs. 28). Overall, the number of children and adolescents admitted to the hospital for surgical treatment increased more than 4-fold (by 332.0 %) during the periods under review, while the number of complicated spinal injuries increased less than 2-fold (86.7 %). Therefore, it is obvious that the increasing number of operated children is not proportional to the increasing number of patients with a complicated fracture and, accordingly, is primarily associated with patients without neurological symptoms but with signs of instability and deformity. It is reasonable to assume that this is the cohort that has remained beyond the focus of pediatric traumatologists and neurosurgeons. It should be mentioned that the proportion of patients with complicated spinal cord injury decreased from 68.2 % (in 2010–2016) to 29.4 % (in 2017–2023) because of an increased number of patients operated on for orthopedic indications).

The distribution of patients by level of injury showed that over 7 years the number of cervical spine surgeries increased in proportion to the total number of operated patients by 300 %

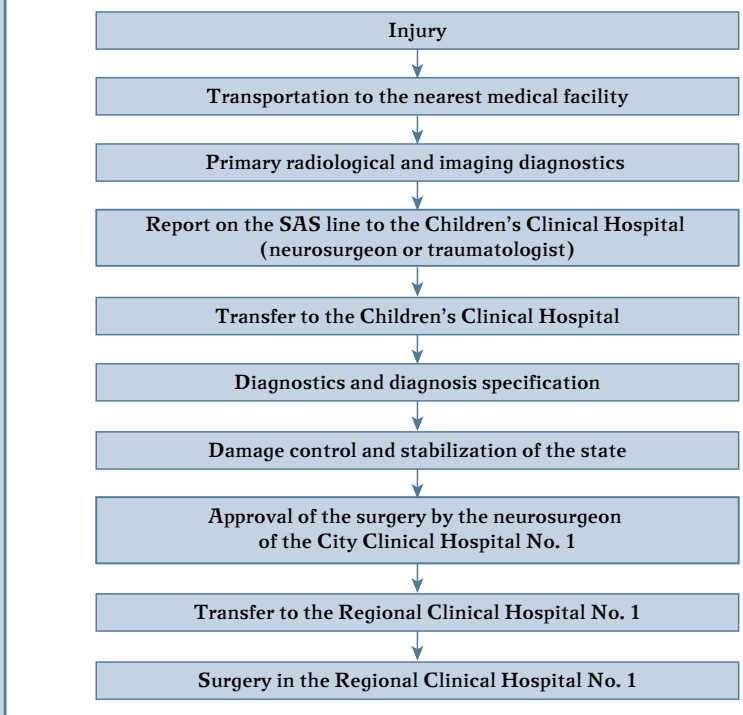

Fig. 1
Algorithm (flow chart) for providing care to children with spinal injuries in 2010–2016

(from 8 to 32 people), while the number of patients with complicated injuries increased by 220 % (5 vs. 16). The number of patients with thoracic injuries increased by 250 % (from 8 to 28), while the proportion of complicated injuries increased by only 66.7 % (6 vs. 10). The greatest changes were found at the level of lumbar spine injuries. The increased number of injuries in this segment was 466.7 % (from 6 to 35); meanwhile, the number of complicated injuries decreased 2-fold (4 vs. 2).

The following types of injuries were diagnosed in patients operated on in 2010–2016 according to the AO classification: in the subaxial area of the cervical spine – A3, A4, C; in the thoracic spine – A3, A4, B2, C; and in the lumbar spine – A4, B2, C. In 2017–2023, the whole range of injuries was observed, except for B3 type fractures. Moreover, the most frequent types of injuries were A3, A4, and C.

The time from injury to the start of surgical treatment is of overwhelming importance in the presence of a primary neurologic deficit. The organizational mechanisms of transporting the patient and the availability of the team to perform the emergency procedure are of utmost importance during this period (Table 2).

The time analysis of the start of surgical treatment of the patients in 2010–2016 showed that out of 15 (100 %) patients with neurologic deficit after injury, only one (6.7 %) patient underwent surgery within 24 hours. Surgical treatment was performed in the period of 2–3 days in 3 (20.0 %) patients. Most frequently, surgical treatment was performed in the time range of 4–7 days. There were 7 (46.7 %) such patients. Another 4 (26.6 %) underwent surgery more than 8 days after the injury.

Two (28.6 %) patients with neurologically uncomplicated injury underwent surgery within 4–7 days, 3 (42.8 %) patients – within 8–14 days, and 2 (28.6 %) patients – within 15–30 days.

After introducing organizational changes in the system of care for children with spinal cord injuries in 2017–2023, the following outcomes were obtained: 20 (71.4 %) of 28 (100.0 %) patients with complicated spinal cord injury were brought to the hospital and underwent surgery within the first 24 hours of injury, and another 4 (14.3 %) patients underwent surgery on days 2–3 after forced preparation and stabilization of their condition. Only four patients underwent surgery after three days because of the combination of injuries and severity of trauma: 2 (7.1 %) underwent surgery within 7 days, one (3.6 %) – on day 13, and one (3.6 %) on day 15 after the injury.

Thirty nine (58.2 %) of 67 patients with unstable spinal cord injuries underwent surgery in the first week after injury, including 14 (20.9 %) in the first 72 hours, 27 (40.3 %) in the period from 3 to 7 days, 27 (40.3 %) in the period from 15 to 30 days after injury, and only 1 (1.5 %) in the period of more than 1 month after injury.

Therefore, by changing the routing of patients according to the type of centralization, it was possible to reduce the decision-making time for surgery, optimize the time to treatment, and improve the diagnostic accuracy that had a positive effect on the clinical outcomes of pedi-

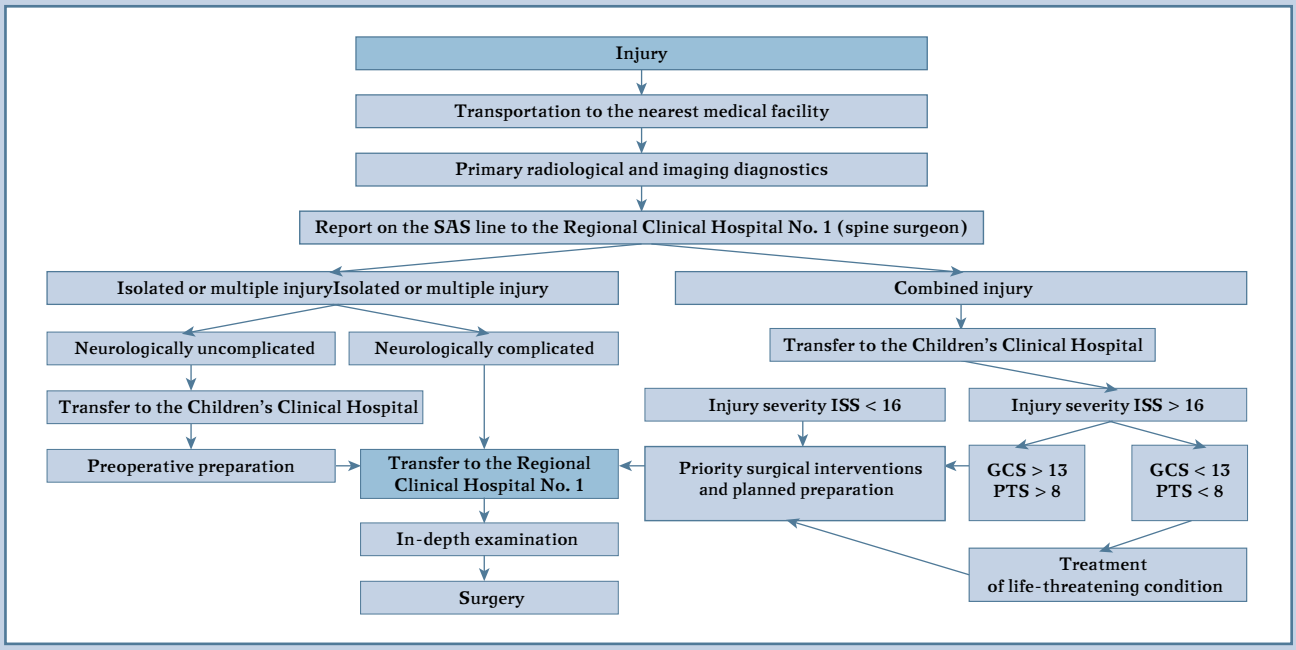

Fig. 2
Algorithm (flow chart) for providing care to children with spinal injuries in 2017–2023

Table 1
Main features of patients with spinal injuries who underwent inpatient surgical treatment in 2010–2016 and 2017–2023

Parameters		2010–2016	2017–2023
Gender, n (%)			
Boys		13 (59.10)	64 (67.37)
Girls		9 (40.90)	31 (32.63)
Age, years			
0–5		0 (0.00)	1 (1.05)
5–10		1 (4.54)	2 (2.11)
10–14		4 (18.18)	14 (14.74)
14–17		17 (77.27)	78 (82.10)
Injured area, n (%)			
Cervical spine	Craniovertebral junction (C0–C1–C2)	0 (0.00)	5 (5.30)
	Subaxial area (C3–C7)	8 (36.40)	32 (33.60)
Thoracic spine		8 (36.40)	28 (29.50)
Lumbar spine		6 (27.20)	35 (31.60)
Neurological complications, n (%)			
Yes		15 (68.18)	28 (29.47)
No		7 (31.82)	67 (70.53)

atric patients. Optimization of inpatient care time resulted in cost reduction of treatment for a patient that demonstrated cost advantage.

Discussion

All injuries in children are fundamentally divided into the following categories: compression and comminuted ones [5]. Compression fractures (AO Spine type A1), accounting for up to 80% of all spinal injuries, do not require surgery and are managed using conservative therapy under the supervision of an traumatologists-orthopedists with certain recommendations.

Comminuted fractures are commonly referred to injuries of the AO Spine classification types A2, A3, A4, B1, B2, B3, and C. Each of them contains fragments of larger or smaller size, which may be directed either towards the spinal canal or in any other direction [6]. These injuries, in addition to possible neurologic deficit, often have signs of instability and cause the formation of post-traumatic deformity. Consequently, most of these types of injuries require surgical treatment in a specialized medical facility.

Specialized medical care for pediatric patients with spinal cord injuries is a major challenge for the health care system. At first sight, the situation is quite simple and obvious. The pediatric service represented by traumatologists-orthopedists and neurosurgeons should be the main component in solving existing problems within the functional area of responsibility. Nevertheless, the absolute number of patients requiring surgery is not significant and may reach 15–20 per year per total population of a region of more than 6,000,000 people, while in regions with smaller populations it may reach 5–10 injured per year. It is clear that this small number of patients cannot provide sufficient and constantly maintained theoretical and practical experience for practicing physicians. According to V.I. Perkhov [7], it is essential to perform 90–154 surgeries per year to maintain the existing skills of a surgeon. The achievement of such quantitative indicators is possible only with the introduction of the principle of centralization of specialized medical care in large federal or regional healthcare centers [8]. At the same time, the surgical experience should be multidisciplinary and consist of the ability to treat patients with injuries, deformities, and degenerative disc diseases.

Pediatric service analysis regarding patients with spine diseases showed that the number of individuals who underwent surgical treatment in 2010–2016 was quite low (22 in 7 years). S.V. Vissarionov et al. [9] revealed that the current state of pediatric spine service in the Russian Federation is far from ideal, and the majority of spinal injuries, especially those related to unstable fractures, are not diagnosed, while the necessary surgeries for spinal injury are not performed for one reason or another. Only some constituent entities keep a total record of all patients affected and perform surgical treatment when necessary. Indirect confirmation of the undercounting of patients injured, especially those without neurologic deficit, is the relationship in the category "complicated/uncomplicated." In most foreign countries and some constituent entities of the Russian Federation, where the activity in this aspect is well enough, the number of patients with neurological complications is 19–20 % in relation to the patients without neurologic deficit [10]. Surgery is used mainly in patients with complications, while patients without neurologic deficit and with unstable and relatively stable compression-comminuted fractures are treated in a conservative manner. This has resulted in a cohort of patients with persistent pain syndromes, secondary neurological complications, and post-traumatic deformities. Their treatment, as a rule, is performed at the age of over 18 years old according to completely different principles and with higher risks of adverse outcomes [11].

Considering the state of the problem, structural organizational changes have been made to the system of providing specialized medical care for pediatric patients with spinal cord injuries in Krasnodar region. The primary consultation of a patient was performed by experienced doctors of the spine unit of the adult regional hospital, and if necessary, the patient underwent surgery at the same hospital.

Table 2
Timing of surgical treatment depending on the injured spinal area and the presence of neurological complications

Time to surgery	2010–2016							2017–2023						
	Complicated injury			Uncomplicated injury			Total	Complicated injury			Uncomplicated injury			Total
	CS	TS	LS	CS	TS	LS		CS	TS	LS	CS	TS	LS	
Up to 24 hours	1	–	–	–	–	–	1	12	6	2	–	2	–	22
2–3 days	1	2	–	–	–	–	3	3	1	–	6	3	3	16
4–7 days	3	2	2	1	1	–	9	1	1	–	6	4	15	27
8–14 days	–	2	2	2	1	–	7	–	1	–	4	4	9	18
15–30 days	–	–	–	–	–	2	2	–	1	–	1	4	5	11
31–60 days	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Over 60 days	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	5	6	4	3	2	2	22	16	10	2	17	18	32	95

CS – cervical spine; TS – thoracic spine; LS – lumbar spine.

Therefore, a new routing plan and algorithm for the management of pediatric patients was developed in the considered region of the Russian Federation, resulting in a more than 4-fold increase in the number of operated patients in 2017–2023. Moreover, the number of patients with neurologic deficit increased less than 2-fold. Accordingly, the rate of patients in the category "complicated/uncomplicated" changed from 68.18 % (in 2010–2016) to 29.43 % (in 2017–2023).

The increased number of operated patients has been attributed to several factors. This is certainly natural population growth, an increased share of tourism, and a change in the view of the medical staff on patients with spinal cord injuries in the context of "surgical/nonsurgical." The first two factors are of the least significance.

The population of Krasnodar region as of January 1, 2022, is reported to be 5,682.0 thousand people; the child population as of the beginning of 2021 was 1,192.7 thousand people, and it has increased by 19.4 thousand (1.7%) over 3 years. The growth of seasonal tourist flow is associated with an increased incidence of injuries among visitors. The retrospective analysis shows that there were 2 (9 %) tourists injured in 2010-2016 and 9 (11.6 %) tourists in 2017–2023.

We relied on the standard of specialized medical care for adults and children with spine, spinal cord, and nerves of the spinal cord injury (an appendix to the order of the Ministry of Health of the Russian Federation No. 639n as of November 7, 2012) when providing medical care in an adult hospital. Two fundamental factors formed the basis for the routing of injured children: the presence of neurological symptoms and the presence of combined injuries. When an isolated complicated spinal cord injury occurred, the children were admitted to the Regional Clinical Hospital (RCH) No. 1, examined by an attending pediatrician, and received specialized surgical care as soon as possible. The patients were treated in cooperation with a pediatrician in the postoperative period and, if necessary, with subject matter experts of the Children's Regional Hospital (CRH). In case of uncomplicated spinal cord injury, the patients were transferred to the CRH, where they were prepared for surgery, and after advanced examination, the patients were transferred to the RCH No. 1 for surgery.

The management of combined injury in children is extremely challenging. The most common reason for inappropriate or delayed specialized medical care for children with combined injuries is organizational aspects that include failure to comply with routing principles and lack of conditions and equipment for high-tech diagnostic examinations, procedures, and surgeries [12–15].

In case of combined injury, children were transferred to the CRH, where their condition was evaluated using the Glasgow Coma Scale (GCS), Injury Severity Score (ISS), and Pediatric Trauma Scale (PTS; Fig. 2). Following diagnostic procedures, if necessary, emergency surgery was performed to eliminate life-threatening conditions and stabilize the patient. Then repositioning and fixation surgeries of the extremities or pelvic ring were performed. After stabilization of the patient's condition, the patient was transferred to RCH No. 1 for spine surgery. The use of an algorithm based on the 'damage control' principle and early life-saving surgeries in the next hours after injury resulted in rapid stabilization of the condition and facilitated the earliest possible transfer of patients to a specialized center for the treatment of spinal cord injury.

The time from injury to surgery is significant. This is especially relevant for patients with neurologically complicated injuries, who should be transported to a specialized clinic for surgery as soon as possible. According to the AO Spine 2024 guidelines, early surgical treatment (<24 hours after injury) compared to late one (>24 hours) results in clinically significant improvement in neurological status [13, 16].

Organizational change in the system of specialized care for patients with spinal cord injuries in Krasnodar region has significantly reduced time from injury to surgery. For example, 20 (71.43 %) of 28 patients with neurologically com-

plicated injuries were delivered to the hospital and underwent surgery within 24 hours from the moment of injury. At the previous stage (before 2017), only one patient (6.67 %) underwent surgery within the first 24 hours. The reason for this is the multiple stages of interaction between the various medical bodies dealing with the patient, and the time spent on examining the patient and approving the transfer to a specialized hospital.

The analysis of the reasons for spinal cord injury showed the following. Serious spinal injuries between 0 and 10 years of age are extremely rare, accounting for no more than 4 % of fractures necessitating surgery, and are caused by high-energy injuries mainly as a result of traffic accidents or falls from height. The ordinary physiological activity of young children is undoubtedly associated with injuries, but the anatomical features of the children's spine and the low energy of injury largely predetermine the onset of mild spinal injuries or compression fractures.

The next age group (10–14 years) comprises 15.4 % of all pediatric patients. In this age range, in addition to traffic accidents and falls from a height, the reasons for spinal cord injury are activities typical of active adolescents (diving, falling from a high bar, etc.).

The highest number of serious spinal injuries is in the age range of 14–17 years old (81.2 %). In this case, spinal injuries arise both as a result of traffic accidents and catatrauma, which are common for any age, and as a result of sports-related injuries and home accidents. Early adulthood is characterized by hyperactivity and high-risk decision-making because of hormonal changes and the use of various psychotropic medications or alcohol. It should be emphasized that in most cases, the spine is already matured and is not much different from the adult spine; it has lost a certain plasticity typical for young children.

Because of more pronounced physiological activity and mental features, spinal cord injuries are twice as frequent in boys than in girls.

Conclusion

Spinal cord injuries in children are quite common; however, the number of fractures requiring surgery is relatively low, ranging up to 17–22 per 1 million population. The small absolute number of patients requiring surgery does not ensure accumulation and maintenance of sufficient experience and skills are among healthcare specialists. This is one of the major challenges related to the difficulties in interpreting the obtained radiology images, determining the indications for surgery, as well as performance of the surgical procedure.

Centralization of specialized medical care for children with spinal injuries in a functioning spine surgery unit of an adult hospital equipped with appropriate infrastructure (including instrumentation for children of all age groups) and routine use of various surgical techniques provides a unified approach to the principles of diagnosis and treatment of this category of patients with favorable outcomes. After changing the routing algorithm for pediatric patients, there is a multiple increase in the number of operated patients within the optimal period after spinal cord injury. These outcomes are achieved when an adult hospital specialist has received training and masters practical skills in the approach and surgical management of traumatic spinal injuries in pediatric patients. The described variant of specialized surgical care for children with unstable and complicated spinal cord injuries may exemplify the organizational model of implementing high-tech care for children in the Russian Federation regions.

The obtained data provide a broader understanding of the social and clinical aspects of medical care for traumatic spinal cord injuries in pediatric patients and identify optimal solutions for its further improvement.

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All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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