PATHOGENETIC FOUNDATIONS FOR PREVENTION OF INCREASED BLOOD LOSS IN SURGERY FOR IDIOPATHIC SCOLIOSIS

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Objective. To analyze risk factors for the development of increased blood loss during surgical correction of idiopathic scoliosis.
Material and Methods. A total of 395 patients with idiopathic scoliosis were operated on using hybrid instrumentation, in prone position, under inhalation multicomponent anesthesia. Four groups of patients were identified: Group I — blood loss below 15 % of total blood volume (TBV) (n = 201); Group II — blood loss 15–30 % of TBV (n = 133); Group III — blood loss 30–40 % of TBV (n = 42); and Group IV — blood loss more than 40 % of TBV (n = 19). In 92 patients, operations were performed under condition of incomplete decompression of the anterior abdominal wall, in 303 patients — under condition of complete decompression. Analysis included data on increased intra-abdominal pressure, the initial condition of the system regulating the aggregate state of blood, the presence of connective tissue dysplasia, and structural features of the bone tissue.
Results. Complete decompression of the anterior abdominal wall during posterior instrumental correction allows reducing the volume of intraoperative blood loss by 60 % and avoiding blood transfusion in 75.9 % of patients. Structural and chronometric hypocoagulation associated with the inhibition of lateral aggregation of fibrin, is a start functional state of the hemostasis system in 80.0 % of patients with idiopathic scoliosis.
Conclusion. The main importance in solving the problem of reducing the severity of intraoperative blood loss belongs to the correction of the revealed disorders in the system regulating the aggregate state of blood and the implementation of procedures aimed at preventing an increase in intra-abdominal pressure.
Key Words: idiopathic scoliosis, posterior fusion, intraoperative blood loss, prevention of increased intra-abdominal pressure, connective tissue dysplasia.

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It is known that the volume of intraoperative blood loss is carefully evaluated during surgical correction of scoliosis [18, 20, 22, 25]. Implementation of advanced techniques for surgical treatment of idiopathic scoliosis, in particular the sophisticated transpedicular fixation technique, is characterized by increased level of surgical aggression due to the need for multi-level spinal stabilization [4]. This leads to a longer duration of surgery and inevitable blood loss, which is an additional factor of operational and anesthetic risk and causes many complications, including deaths [21, 23, 35]. The major known factors causing intraoperative blood loss during surgical correction of scoliosis include the extensive area of unavoidable traumatization of muscle and bone tissues, long duration of surgery, and increased intra-abdominal pressure [26, 28]. Some researchers [12, 32, 34] showed quite close relationship between the duration of the operation, severity of spinal deformity and its etiology, character of hemodynamics, anesthetic management, and intraoperative blood loss. Other researchers [9, 16, 24, 35] did not observe this correlation dependence and found only positive correlation between the volume of intraoperative blood loss and extensiveness and duration of surgery. There is evidence that the number of vertebrae included in the fusion zone is the most significant factor affecting the severity of blood loss. There are reports that the volume of intraoperative blood loss is higher in patients with low bone density than in patients with normal bone density.

The literature describes cases of pathological bleeding associated with connective tissue abnormalities [6]. Thus, the state of increased tissue bleeding was observed in patients with Marfan and Ehlers – Danlos syndromes, prolapse of heart valves, congenital heart disease and other diseases associated with connective tissue dysplasia. The pathogenesis of bleeding remained unclear for a long time. Some authors attributed it to thrombocytopathies [3, 13, 19]. There are some publications dealing with hemostatic disorders and their impact on the intensity of bleeding during surgery in patients with scoliosis. There is evidence that this category of patients have impaired aggregation function of platelets, decreased activity of von Willebrand factor and factor VIII, impaired polymerization of fibrin monomers, and hypercoagulation shifts, whose severity depends on the severity of the disease [10, 29].

Changes in plasma parameters of hemostasis system during spinal surgery in the form of hypofibrinogenemia and suppressed fibrinolytic activity of blood were reported. At the initial stages of surgical intervention, the authors regarded these hemostatic reactions as compensated ones, which transformed to subcompensation state later into the follow-up [2].

Therefore, the literature data suggest that there is a combination of factors determining the resulting volume of intraoperative blood loss during surgical correction of idiopathic scoliosis. However, the causes of the increased, in some cases massive, blood loss should be clarified in order to develop possible preventive methods aimed at reducing intraoperative blood loss and, consequently, improving the safety of patients operated on for idiopathic scoliosis.

These circumstances gave rise to formulation of the objectives of the present study.

The objective of the research was to analyze the risk factors for the development of increased blood loss during surgical correction of idiopathic scoliosis.

Material and Methods

Here we report an observational study carried out during surgical treatment of 395 patients with idiopathic scoliosis, who underwent elective surgery at the Department of Pediatric Orthopedics No 1 of the Novosibirsk RITO n.a. Ya.L. Tsivyan in 2011–2015. Inclusion criteria were as follows: adolescent and juvenile patients with idiopathic scoliosis who were operated on for the first time for spinal deformities. Exclusion criteria were as follows: patients with blood diseases, diagnosed differentiated connective tissue dysplasia, and patients who were operated on using a multi-stage treatment technique. The study was approved by the ethical committee of the Research Institute for Traumatology and Orthopedics n.a. Ya.L. Tsivyan (protocol No 006/11 of 25.03.2011).

Recorded volume of intraoperative blood loss was used as a criterion to form study groups. WHO classification 2001 was used to assess the severity of intraoperative blood loss.

Four groups of patients were formed:

I (n = 201) – grade I intraoperative blood loss (up to 15 % of the TBV);

II (n = 133) – grade II intraoperative blood loss (15–30 % of the TBV);

III (n = 42) – grade III intraoperative blood loss (30–40 % of the TBV);

IV (n = 19) – grade IV intraoperative blood loss (more than 40 % of the TBV).

The average age of patients was 17.2 [14.24; 20.36] years in group I, 16.9 [13.56; 20.04] years in group II; 16.5 [13.08; 19.92] years in group III; 16.7 [13.01; 20.39] years in group IV. The indications for surgical treatment included grade IV spinal deformity in 301 (76 %) patients and grade III spinal deformity in 94 (24 %) patients.

All patients underwent surgical correction of spinal deformities, including dorsal spinal fusion with hybrid instrumentation. Operations were performed in patient's prone position. In 92 patients, an inflatable rubber ring placed under patient's belly was used to prevent increase in abdominal pressure. In 303 patients, dorsal correction was carried out on a special table for spinal surgery. Modular design of the table enabled avoiding any external influence on the patient's abdominal region.

We studied and analyzed the factors that determine the extent of intraoperative blood loss, such as increased intra-abdominal pressure, initial state of the system of regulation of the aggregate state of blood (RASB), dysplasia of connective tissue, and structural features of bone tissue.

Preoperative examination was carried out using a uniform standard program. In 197 (49.9 %) patients, the following parameters were additionally assessed: thrombin time, fibrinolytic activity of blood, von Willebrand factor, antithrombin III, plasminogen, protein C, protein S, as well as blood coagulation factors VIII, X, and XII .

Functional status of SRBA was assessed by studying the hemostatic potential (HP) of the whole blood. Hardware-software system ARP-01M Mednord, functioning based on recording the changes in resistance of the investigated medium to resonant oscillations of the resonator needle mounted on the piezoelectric element and placed into the cuvette with patient's blood, was used to study HP. All calculations, plotting of graphs and numerical parameters of the study, as well as the system operational management was carried by a personal computer with specialized computer program X hemo-3. The dynamics of the process under study was determined based on changes in aggregation state of blood and recorded in the form of the integrated curve of the low-frequency piezoelectric thromboelastography, every point of which was determined by the state of the system at a particular time. The studied parameters and their reference values are shown in Table 1.

Preoperative densitometry was carried out in 80 (20.3 %) of patients. Mineral density of bone tissue was assessed by dual-energy X-ray absorptiometry (DEXA) using axial osteodensitometer Hologic, with children's programs and US regulatory age database. These patients also underwent morphological examination of the articular processes of the lumbar vertebrae obtained during surgery.

The presence of signs of connective tissue dysplasia was evaluated by physical, instrumental, and ultrasound examination. Phenotypic signs of connective tissue dysplasia were evaluated using the L.N. Abakumova scale by scoring clinical manifestations [1].

Standard 12-lead ECG was carried out on the 3/6-channel electrocardiograph BIOSET 3700, echocardiography and examination of internal organs were carried out using Aplio XG ultrasonograph.

All operations were performed under general anesthesia based on sevoflurane, fentanyl, clonidine, and ketamine. There were no significant differences between the groups in the tactics used to select the extent and quality of infusion-transfusion management.

Intra-abdominal pressure was controlled using the indirect method suggested by Collee et al. [15]: intubation of trachea was followed by insertion of gastric tube; intragastric positioning of the tube was confirmed by aspiration of gastric juice and increase in the abdominal pressure when pressing on the epigastric region.

Intraoperative blood loss was assessed by gravimetric method and measurement of blood volume aspirated into graduated containers. Proper TBV was determined according to the formula: TBV = Pq, where P is patient's body weight (kg); q – empirical number reflecting blood volume per 1 kg of body weight (children aged 6–12 years – 80 ml/kg, over 12 years and adults – 70 ml/kg, Russian State Standard (GOST) R 53470 – 2009).

Statistical calculations were carried out using Rstudio software. Normality of empirical data distribution was tested using Kolmogorov-Smirnov test (Lilliefors test). Comparative analysis in the groups was carried out using nonparametric methods because of the small and unmatched number of normal values of the groups. Descriptive characteristics are represented as follows: median [first quartile, third quartile], percentage of the total number in the group for categorical data. The study of paired statistical relationships was carried out by calculating the Spearman correlation coefficients, statistical hypotheses were tested at the critical significance level of $p = 0.05$, the difference was considered statistically significant if $p < 0.05$.

Results

Analysis of intraoperative blood loss severity showed that blood loss did not exceed 15 % of the TBV in 50.9 % of patients, ranged from 15 to 30 % of the TBV in 33.7 % of patients; it was significant and corresponded to grade III, 30–40 % of the TBV, in 18.0 % of patients, and it was massive and corresponded to WHO grade IV, more than 40.0 % of the TBV, in 13.4 % of patients.

Table 2 shows the main characteristics of the operations.

During the operation, all patients were placed on an operating table in prone position using various methods to prevent increase in intra-abdominal pressure. Rubber ring provided only partial decompression of the anterior abdominal wall. Hereinafter this method is referred to as incomplete decompression of the anterior abdominal wall. On the contrary, features of the modular structure of the specialized surgical table prevented even minimum compressing effect on the abdominal area and therefore this method preventing increase in intra-abdominal pressure was referred as complete decompression of the anterior abdominal wall. The maximum number of patients operated under conditions of complete decompression of the anterior abdominal wall was included in Group I. The maximum number of patients operated under conditions of partial decompression of the anterior abdominal wall was included in Group III. Proportions of the used methods for prevention of increased intra-abdominal pressure in the groups is shown in Table 3.

Table 4 shows details on the extent of intraoperative blood loss under conditions of various methods for prevention of increase in intra-abdominal pressure.

Table 1

Reference values of the low-frequency piezoelectric thromboelastography

Parameter	Symbol	Limits
Baseline value, relative units	A0	130—250
Amplitude of contact coagulation, rel. units	A1	80—110
Contact coagulation time, min	T1	0.5—1.5
Intensity of contact coagulation, rel. units	ICC	-40 to -10
Thrombin constant amplitude, rel. units	A2	183—203
Thrombin constant time, min	T2	3.5—4.8
Thrombin activity constant, rel. units	TAC	25—40
Amplitude of coagulation drive, rel. units	A3	705—725
Coagulation time (gel point), minutes	T3	5—10
Intensity of coagulation drive, rel. units	ICD	30—45
Clot polymerization amplitude, rel. units	A4	846—866
Clot polymerization time, min	T4	33.5—39.5
Intensity of clot polymerization, rel. units	ICP	15—25
Amplitude of maximum clot density, rel. units	A5	881—901
Formation time of fibrin-platelet structure, min	T5	41—47
Maximum clot density, rel. units	MCD	450—650
Intensity of total coagulation, rel. units	ITC	15—25
Amplitude of retraction and lysis, rel. units	A6	872—892
Retraction and lysis time, min	T6	51—57

According to Table 4, complete decompression of the anterior abdominal wall reduced the volume of intraoperative blood loss by 60.0 %.

Intra-abdominal pressure was controlled using gastric pressure measurement as a simple and safe method, which does not hinder movements of the surgical team. Abdominal pressure was measured only in patients who were operated on under conditions of complete decompression of the anterior abdominal wall. Control of gastric pressure dynamics during the major stages of the operation showed that abdominal pressure values in operated patients were within the normal limits and amounted to 2.2 [0.9; 3,5] mmHg.

Surgical correction of scoliotic deformities of the spine under conditions of complete decompression of the anterior abdominal wall reduced the need for intraoperative use of blood components. No transfusion was performed in Group I; transfusion of blood components was conducted in 36 (27.1 %) Group II patients, 40 (95.2 %) Group III patients, and all Group IV patients.

Morphological examination of the articular processes of the lumbar vertebrae showed structural features of the bone tissue. The most significant of them included atrophy and dystrophy of bone trabeculae, cysts having various sizes in the inter-trabecular spaces, dilated patulous vessels filled with blood, and foci of extensive hemorrhage. This morphological structure of bone tissue was observed in 26 patients. In 20 patients having these morphological changes, intraoperative blood loss was within 31–40 % of the TBV (Group III); in 6 patients, it exceeded 40 % (Group IV).

The results of morphological examination of bone tissue were compared to the results of densitometry. The patients with morphological features showed values that could indirectly indicate varying severity of decrease in mineral bone density (mean Z-test values ≤ 2.5). Although very weak correlation was detected between the bone density value and the volume of intraoperative blood loss in ml and % of the TBV (Spearman correlation coefficient was $r = -0.26$, $p = 0.013$ and $r = -0.35$, $p < 0.001$, respectively), it is reasonable to assume that these morphological features can cause excessive bone bleeding, which results in increased intraoperative blood loss.

When evaluating the presence of signs of connective tissue dysplasia in patients with idiopathic scoliosis, we took into account data of both physical and instrumental examination (US-diagnosis). The following symptoms of connective tissue dysplasia were taken into account during physical examination: gothic palate, abnormal occlusion, hypermobility of joints, clubfoot, flatfoot, O- and X-shaped extremities [5]. Dysplastic signs were detected in 166 (42.0 %) patients. At the same time, 33.3 % of patients had a combination of phenotypic manifestations, such as gothic palate, abnormal occlusion, hypermobility of joints, and flatfoot. In 185 (46.8 %) patients, examination showed changes associated with impaired morphology and function of the internal organs: pathology of the organs of sight (myopia, hyperopia) in 37 (9.4 %) patients; ptosis of internal organs in 47 (11.9 %) patients; dysmotility of the gastrointestinal tract in 58 (14.7 %) patients. Minor anomalies of the heart and ECG changes were the dominating symptoms. Combinations of anatomical and functional disorders were observed in 63.0 % of examined patients.

Detected signs of connective tissue dysplasia were classified into three types: type 1 — phenotypic signs; 2 – visceral signs; 3 – a combination of phenotypic and visceral signs. Table 5 shows percentage of dysplastic status types in study groups.

Table 2

Main characteristics of operations

Parameter	Study groups				Kruskal — Wallis test, p-value
	I (n = 201)	II (n = 133)	III (n = 42)	IV (n = 19)	
Levels of transpedicular fixation, n	4 [3; 5]	4 [3; 5]	4 [3; 5]	4 [3; 4.5]	Overall comparison: 0.839; pairwise comparison**: I—II: 0.966; I—III:> 0.999; II—III: 0.879; I—IV:> 0.999; II—IV:> 0.999; III—IV:> 0.999
Duration of surgery, min	165.0 [140.0; 190.0]	150.0 [130.0; 180.0]	197.5 [166.2; 260.0]	200.0 [180.0; 245.0]	Overall comparison <0.001*; pairwise comparison**: I—II: 0.002*; I—III: <0.001*; II—III: <0.001*; I—IV: <0.001*; II—IV: <0.001*; III—IV: 0.607
Intraoperative blood loss, ml	450 [350; 500]	700 [600; 850]	1100 [950; 1200]	1500 [1250; 1750]	Overall comparison: <0.001*; pairwise comparison**: I—II: <0.001; I—III: <0.001*; II—III: <0.001*; I—IV: <0.001*; II—IV: <0.001*; III—IV: <0.001*
Intraoperative blood loss, % of the TBV	12.0 [10.0; 13.0]	20.0 [17.0; 23.0]	34.0 [30.3; 36.0]	45.0 [43.5; 53.0]	Overall comparison <0.001*; pairwise comparison**: I—II: <0.001; I—III: <0.001*; II—III: <0.001*; I—IV: <0.001*; II—IV: <0.001*; III—IV: 0.329

*significantly different values;

**for pairwise comparisons, Mann—Whitney U-test was used; Benjamin—Hochberg correction was used to account for the effect of multiple comparisons.

Table 3

Fractional distribution of the methods used to prevent increase in the abdominal pressure, %

Decompression type	Study groups				Fischer's exact two-sided test, p-value
	I	II	III	IV	
Incomplete decompression of the anterior abdominal wall (n = 92)	13	30	40	17	<0.001
Complete decompression of the anterior abdominal wall (n = 303)	63	34	2	1	

The data on the intraoperative blood loss in patients with established type of dysplastic status show that the highest extent of intraoperative blood loss was observed in the case of type 3 connective tissue dysplasia, and the percentage of patients with type 3 was the highest in Group IV (Table 6).

Preoperative laboratory study of hemostatic system showed that the mean values of most parameters were within the conditional normal range. Average platelet count was 228.3 [199.0; 257.0] x 109 in Group I, 247.0 [214.0; 299.0] x 109 in Group II, 269.0 [212.5; 307.0] x 109 in Group III, 238.0 [214.5; 265.5] x 109 in Group IV (group comparison based on Kruskal-Wallis test; $p < 0.001$). Averages values of fibrinolytic activity were above normal in Groups II and III, but intergroup comparison detected no statistically significant differences of these values. There was also no statistically significant correlation between the baseline results of laboratory tests for hemostasis values and volumes of intraoperative blood loss.

Blood HP test using LPTEG method, which assesses the entire coagulation cycle, was conducted in 82 (20.9 %) patients, where 67 patients were included in group I, 12 – in II, 3 – in IV. Data of all patients were analyzed in order to identify characteristics features in patients with investigated pathology. Three types of HP were determined.

The first type of HP was detected in 67 (81.7 %) Group I patients (Table 7). The data show that characteristic features of the vast majority of patients included structural hypocoagulation, i.e. reduced intensity of coagulation drive (ICD), intensity of clot polymerization (ICP), maximum clot density (MCD), and chronometric hypocoagulation, i.e. increase in clotting time t3, formation time of fibrin-thrombocytic structure t5, eventually reducing the intensity of total coagulation (ITC). At the same time, the response of the vascular thrombocytic element, i.e. contact coagulation time t1, intensity of contact coagulation (ICC), and fibrinolytic link, i.e. intensity of clot retraction and lysis (ICRL), provided adequate HP response to surgical trauma. In the case of this type of HP, intraoperative blood loss corresponded to grade I and it was no more than 12 % of the TBV. This fact led to conclusion that the state of hemostatic system was characterized by adequate and effective self-regulation in the vast majority of patients with idiopathic scoliosis.

The second type of HP was observed in 12 (14.6 %) Group II patients (Table 8). The characteristic features of this type of HP included chronometric hypocoagulation (increased t3 and t5, reduced ITC) and structural hypercoagulation (increased MCD). Detected imbalance of blood HP was probably caused by inadequate response of hemostasis system to the action of aggression factors, such as surgical trauma, exposure to medicinal products for anesthesia and infusion management of the operations. This is evidenced by the resulting data on the volume of intraoperative blood loss, which corresponded to WHO grades II and III and was within 28–30 % of the TBV. These data suggested that this type of HP corresponds to hemostatic system imbalance.

The third type of hemostatic potential was observed only in three patients, where similar HP disorders were detected in all cases, such as pronounced activation of the initial stages of fibrinogenesis, i.e. intravascular activation of aggregation activity of blood cells ($t1 \rightarrow 0$; $ICC \rightarrow 0$), with underlying disorders of lateral assembly of fibrin (decrease in ICP) typical of patients with idiopathic scoliosis. Activation of vascular thrombocytic hemostasis element was accompanied by significant activation of the thrombin activity (TAC = 50; 100; 60 relative units), respectively accompanied by increased anticoagulation activity (CTAA = 3.3, 5.0, and 3.2 relative units), reduc-

Table 4

The volume of intraoperative blood loss with prevention of increase in intra-abdominal pressure by various methods

Parameter	Incomplete decompression of the anterior abdominal wall (n = 92)	Complete decompression of the anterior abdominal wall (n = 303)	Mann – Whitney U-test, p-value
Blood loss ,ml	1100 [937.5; 1212.5]	500 [400.0; 650.0]	<0.001
Blood loss, % of the TBV	30 [24.5; 38.0]	14 [11.0; 18.0]	<0.001

ing the coagulation potential at the proteolytic stage (ICD = 36; 60; 24 relative units), and activation of fibrinolytic activity of ICRL. Intraoperative blood loss in these patients was graded as massive and exceeded 50% of the TBV. The obtained data suggest that this type of HP corresponds to dysregulation of hemostasis system. Fig. shows piezoelectric thromboelastogram in a patient with type III HP.

Discussion

The findings of the study are completely consistent with the available literature data, demonstrating that intraoperative blood loss during surgery for scoliosis varies in wide range [27, 30, 31, 33]. When speaking about the factors determining the severity of intraoperative blood loss, the majority of Russian and international researchers use the principle "there is a factor – there is a risk", but do not provide specific information about the importance of each of them and possible effective methods for prevention and treatment measures aimed at reducing blood loss.

Our study determined the main factors contributing to intraoperative blood loss in surgery for idiopathic scoliosis and clarified the significance of each of them in this group of patients. The fact that surgical correction of scoliotic deformities of the spine is carried out in non-physiological patient's position on the operating table (prone position) with varying severity of the anterior abdominal wall compression is of primary importance. Since the abdominal cavity is a closed space, the pressure therein increases in all directions in accordance with Pascal's law. The pressure on the posterior wall of the abdominal cavity accompanied by blood flow disturbance in the inferior vena cava is believed to be the most significant factor. Blood outflow to the right heart includes activation of the vertebral system, resulting in increased intraoperative bleeding of the tissue. Various options of patient's positioning on the operating table are used to reduce the pressure on the anterior abdominal wall [26, 28]. Based on statistically significant data, it was conclusively demonstrated that the use of intraoperative placement of the patient in prone position with full decompression of the anterior abdominal wall prevents the effect of increased intra-abdominal pres-

Table 5

Fractional distribution of the type of dysplastic status in the study groups, %

Groups	Type of dysplastic status			Fischer's exact two-sided test, p-values
	1st	2nd	3rd	
I	35	38	27	I:II 0.715; I:III 0.040*; I:IV <0.001*; II:III 0.021; II:IV < 0.001*; III:IV 0.004*
II	28	34	38	
III	7	36	57	
IV	5	0	95	

*significantly different values.

Table 6

Intraoperative blood loss in patients with established type of dysplastic status

Parameters	Type of dysplastic status			Kruskal — Wallis test, p-value
	1 n = 65 (16.5%)	2 n = 84 (21.3%)	3 n = 101 (25.6 %)	
Blood loss, ml	450 [450; 700]	520 [500; 850]	1100 [650; 1250]	Overall comparison: <0.001*; pairwise comparison**: 1—2: <0.001*; 1—3: <0.001*; 2—3: <0.001*
Blood loss, % of the TBV	14.0 [12.0; 19.0]	14.0 [14.0; 25.3]	28.0 [14.0; 36.0]	Overall comparison: <0.001*; pairwise comparison**: 1—2: 0.002*; 1—3: <0.001*; 2—3: <0.001*
Levels of transpedicular fixation, n	4 [3; 5]	4[3; 5]	4 [3; 5]	Overall comparison: 0.764; pairwise comparison**: 1—2: >0.999; 1—3: 0.891; 2—3: 0.815
Duration of surgery, min	170.0 [150.0; 195.0]	157.5 [130.0; 186.2]	190.0 [165.0; 240.0]	Overall comparison: <0.001*; pairwise comparison**: 1—2: 0.193; 1—3: 0.004*; 2—3: <0.001*

*significantly different values;

**for pairwise comparisons, Mann — Whitney U-test was used;

Benjamin — Hochberg correction was used to account for the effect of multiple comparisons.

sure at all stages of surgery and minimizes the severity of intraoperative venous bleeding. This is confirmed by the fact that intraoperative blood loss did not exceed 15.0 % of the TBV in 50.9 % of patients, the volume of intraoperative blood loss was within 15–30 % of the TBV in 33.7 % of patients, which enabled avoiding transfusions using donor blood components in 75.9% on operated patients, thus reducing the actual risk of hemotransfusion complications.

Most publications on the bone tissue morphology in patients with idiopathic scoliosis focus on the study of etiological factors and pathogenetic mechanisms of scoliosis. However, the studies that will answer the following questions: whether the particular bone tissue architectonics in patients with idiopathic scoliosis may cause increased bone bleeding and whether preoperative assessment of mineral bone density can provide information about the likelihood of increased intraoperative blood loss in advance, are of great interest. Examination of histologic specimens revealed significant structural features of bone tissue in the form atrophy of bone trabeculae, cysts, and dilated, patulous vessels filled with blood in the inter-trabecular spaces in 32.5 % of patients, who underwent examination. The results of analysis showed that all cases with detected morphological features corresponded to the category of significant intraoperative blood loss, more than 30 % of the TBV. It can be assumed that these changes resulted in excessive bone bleeding, which led to increased intraoperative blood loss. Given the fact that all patients underwent densitometry at the preoperative stage, we attempted to determine the significance of densitometry as a possible predictor of increased intraoperative blood loss. Test results showed decrease in bone density in 20.3 % of patients. This is consistent with findings of other researchers, who reported that abnormal mineral density of lumbar vertebral bodies from osteopenia to osteoporosis was detected in patients with grade III–IV spinal deformities [7]. However, the lack of correlation between the studied parameters suggested that the results of preoperative densitometry should be taken into account in practice, but they cannot be considered as a significant risk factor for increased blood loss and criterion for blood loss prediction, when performing corrective surgery in patients with idiopathic scoliosis.

Dysplastic status is another clinical characteristic of patients with idiopathic scoliosis. High incidence of clinical signs of connective tissue dysplasia suggests that it is the underlying condition in these patients. Previous studies resulted in similar findings in patients with severe scoliosis [8]. No correlation between the presence of the signs of connective tissue dysplasia and volume of intraoperative blood loss was established, and therefore dysplasia may be considered only as an additional risk factor for increased intraoperative blood loss.

At the same time, combination of connective tissue dysplasia with impaired hemostasis is believed to be a natural phenomenon. In particular, increased tissue bleeding at the surgical area was observed in the case of prolapse of cardiac valve leaflets [10]. These data are consistent with the findings of other researchers, who reported that more than 50% of patients with connective tissue diseases can not be attributed to a specific clinical syndrome. Moreover, coalition or partial overlap of syndromes is possible [8]. The study of G.A. Sukhanova [10] showed that blood loss higher than 20.0 % of the TBV was observed only in 29.2 % of patients without baseline hemostatic disorders who were operated on for spinal scoliosis, while in the group with baseline hemostatic disorders this value was 50.5 %. Most likely, it is high incidence of concomitant connective tissue dysplasia and hemostatic dysfunctions that defines cases of increased blood loss during surgical correction of scoliotic deformities of the spine. Phenotypic and visceral signs of connective tissue dysplasia are the underlying condition in 63.5 % of patients with idiopathic

Table 7

The first type of hemostatic potential

Parameter	Reference values	Idiopathic scoliosis (n = 67)
T1	1.30 [0.90; 1.70]	1.40 [0.95; 1.60]
ICC	27 [16; 35]	19 [12.5; 25.0]
TAC	30.0 [25.0; 38.0]	12.0 [10.8; 16.0]**
T3	7.60 [5.90; 9.20]	20.00 [16.85; 25.00]**
ICD	37.0 [32.5; 43.2]	18.0 [14.7; 21.0]**
ICP	16.75 [13.65; 19.65]	7.60 [7.15; 7.85]**
MCD	502.0 [466.0; 560.0]	400.0 [372.5; 556.5]
T5	34 [27; 38]	62 [51; 65]**
ITC	17.04 [14.68; 20.12]	8.80 [7.90; 9.75]**
ICRL	0.90 [0.10; 2.50]	0.00 [0.00; 0.25]*
CTAA	2.35 [1.90; 2.80]	2.10 [1.95; 3.00]

See Table 1 for description of the parameters; ICRL — intensity of clot retraction and lysis; CTAA — coefficient of total anticoagulant activity;
Mann — Whitney U-test: *p < 0.05; **p < 0.001.

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ICRL	0.90 [0.10; 2.50]	0.00 [0.00; 0.25]*
CTAA	2.35 [1.90; 2.80]	2.10 [1.95; 3.00]

See Table 1 for description of the parameters; ICRL — intensity of clot retraction and lysis; CTAA — coefficient of total anticoagulant activity; Mann — Whitney U-test: *p < 0.05; **p < 0.001.

scoliosis and serve as additional risk factors for increased blood loss during surgical correction of spinal deformities.

It is known that surgical aggression is accompanied by appropriate protective reactions of the organism, presenting with increased adhesion and aggregation activity of platelets, enhanced coagulation potential of the blood and anticoagulant activity, and increased fibrinolytic activity of blood. It is this reaction of the hemostatic system that provides hemostasis and prevents excessive formation of thrombin. Thus, surgical and anesthetic aggression are the factors associated with possible thrombogenic or hemorrhagic manifestations as a presentation of compensation/decompensation level of hemostasis system. Given the fact that the pathogenesis of the underlying disease is often accompanied by increase or decrease in activity of all elements of the hemostasis system, detection of the predictors of thrombohemorrhagic complications during surgery planning has not only diagnostic and prognostic value, but in some cases, determines the need for correction of detected disorders [3].

In our research, the study of the functional state of hemostasis system at the preoperative stage was for the first time carried out using global diagnostic test of the RASB system, LPTEG [11]. This technique enabled detecting changes characteristic of the studied pathology. In particular, this applies to disorders of polymerization stage of fibrinogenesis characterized by twofold and stronger inhibition of the process of lateral assembly of fibrin. It was found that observed structural hypocoagulation at the stage of crosslinked fibrin formation and chronometric hypocoagulation at the proteolytic stage were the baseline characteristic of the hemostatic system in most cases. At the same time, detected changes were compensated and ensured an adequate response of blood hemostatic potential to the effect of aggression factors, such as surgical trauma, anesthetics, and medications for infusion management of the operations. This is evidenced by the resulting values of intraoperative blood loss, less than 15.0 % of the TBV in 81.7 % of patients, who were examined using LPTEG. At the same time, we do not rule out that in some cases the blood HP imbalance observed in the form of chronometric anticoagulation with underlying structural hypercoagulation, which was detected in 14.6 % of patients, could play a significant role in disturbance of the adequate response of hemostatic system to surgical aggression and determine increased intraoperative blood loss of more than 15.0 % of the TBV. However, we can in general conclude that the hemostatic system was in the state of adequate and effective self-regulation in the vast majority of patients with idiopathic scoliosis.

In 3.7 % of cases, intraoperative blood loss was massive and amounted to more than 50 % of the TBV. Analysis of data obtained in clinical observations revealed characteristic similar changes in blood HP, such as pronounced activation of aggregation activity of blood cells, significant activation of thrombin activity, enhanced anticoagulant activity, and increased lytic activity of the blood with underlying impairment of the lateral assembly of fibrin were observed. Obviously, surgery caused further activation of vascular, thrombocytic, coagulation, and fibrinolytic elements of the system, which hindered adequate hemostasis and demonstrated dysregulation state of blood HP. This finding is consistent with the opinion of other researchers that the surgery causes intravascular coagulation in the body of operated patient [2]. This led to conclusion that these changes in blood HP detected at the preoperative stage can be considered as predictors of massive intraoperative bleeding. Accordingly, patients with these blood HP disorders constitute a special risk group for the development of hemorrhagic syndrome. This category requires preventive premedication (disaggregants, endothelial protectors) and targeted intraoperative medicamentous correction (systemic antifibrinolytics) [14, 17].

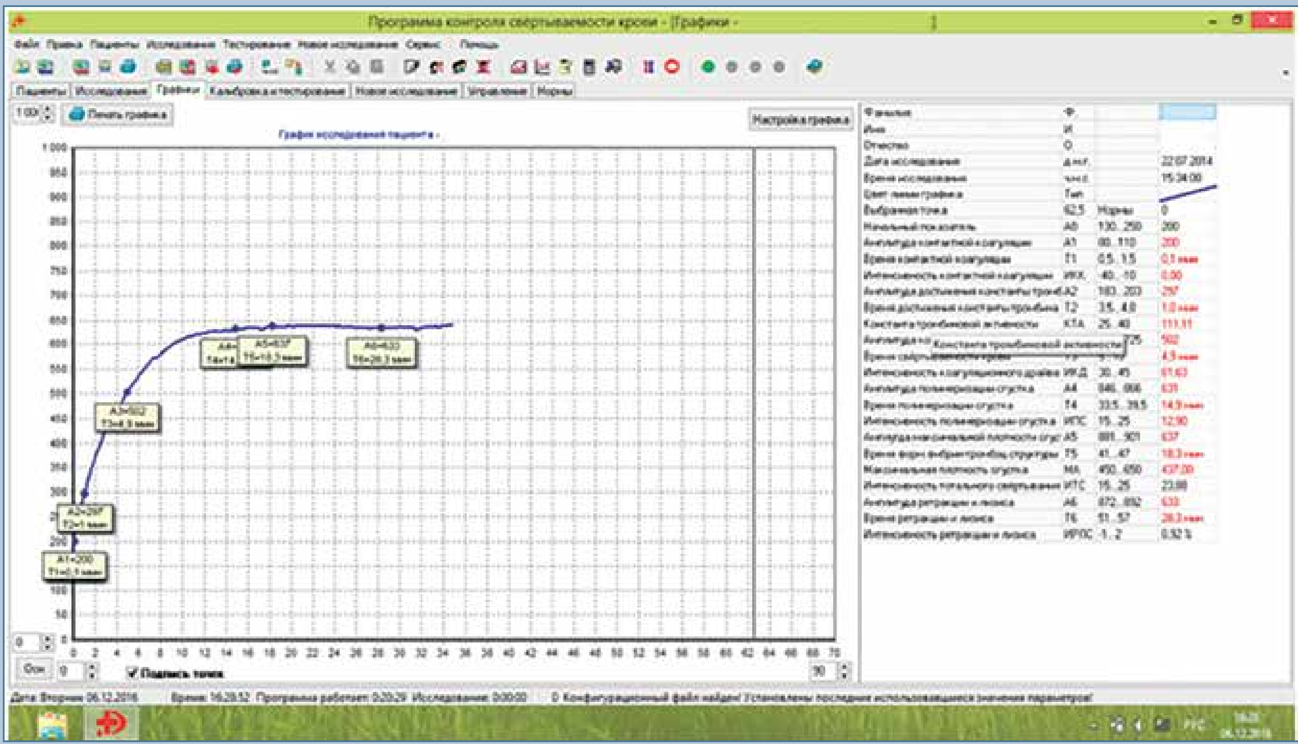

Fig.
Piezoelectric thromboelastogram of patient B., 13 years old

We cannot carry out an adequate comparative assessment of the data on the state of blood HP in patients with idiopathic scoliosis obtained in our research with data obtained by other researchers. This is due to the fact that publications covering studies of the hemostatic system in patients with idiopathic scoliosis describe the changes observed using and analyzing the results of standard coagulologic tests, which do not provide full information about the functioning of all elements of the hemostatic system as a single integrated system. At the same time, it was shown that application of LPTEG method as a global diagnostic test maximizes the possibilities of detecting the underlying hemostatic disorders in patients with idiopathic scoliosis and is a reasonable necessity during preoperative examination. Furthermore, the nature of hemostatic disorders enables personalization of the program of required premedication and intraoperative medicinal correction.

Conclusion

Our study showed that the combination of factors determining the resulting volume of intraoperative blood loss in surgery of idiopathic scoliosis includes increased abdominal pressure, impaired bone structure, signs of connective tissue dysplasia, and underlying hemostatic disorders. Each factor to some extent determines the risk of increased bleeding. It was shown that correction of detected disorders in the RASB and implementation of technological methods aimed at preventing increased abdominal pressure play a key role in solving the problem of reducing the severity of intraoperative blood loss.

The obtained data suggest that full decompression of the anterior abdominal wall is the technological method that justifiably belongs to blood preserving techniques during spinal surgery in the prone position of the patient.

LPTEG method, as a global diagnostic test of the RASB, maximizes the possibility of determining underlying hemostatic disorders in patients with idiopathic scoliosis. Furthermore, it is a justified necessity during preoperative examination, which enables individualization of the program of premedication and intraoperative medicinal correction.

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