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Procedural Complications of Central Venous Catheter Placement in Pediatric Oncology Practice (a Clinical Case Series)

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Summary

The availability of central venous access is the cornerstone of contemporary pediatric oncology and hematology. As a result, the percentage of pediatric patients receiving infusion chemotherapy who require a central line remains high. Central venous catheter insertion can be associated with procedural complications, including life-threatening ones.

Aim to investigate the potential factors leading to complications during central venous catheterization in order to develop preventive strategies.

Materials and methods. The study included 1,512 original cases of patients aged 1 month to 20 years treated at the D. Rogachev National Research Medical Center between 2019 and 2022. The following 10 complications were examined: failed first venipuncture attempt, guidewire/catheter malpositioning, guidewire knotting, life-threatening arrhythmias, guidewire entrapment in the trabecular network of the right ventricle, arterial puncture, pneumothorax, hemothorax, puncture of lung parenchyma, Horner's syndrome. In addition, four rare complications were noted, including phrenic nerve injury, cardiac tamponade, alveolar hemorrhage, and arterial pseudoaneurysm.

Results. The primary cause of all complications was direct mechanical injury to anatomical structures by a needle or guidewire/catheter. When inadvertent vascular injury and bleeding occur, the resulting hematoma may lead to further damage by compressing soft tissues. Excessively deep insertion of the guidewire may cause its knotting or cardiac arrhythmias. Adequate physician training and strict adherence to procedural protocols are essential to avoid these complications.

Conclusion. Central venous catheterization remains a procedure with potential complications. Although ultrasound guidance does not eliminate all risks, it increases the likelihood of successful venipuncture at the first attempt, thereby reducing complication rates. Recognizing the potential causes of procedural complications during central venous access placement, including uncommon ones, facilitates early diagnosis and appropriate medical intervention.

Keywords: central venous catheter; central venous catheterization in children; complication of central venous catheter placement in children; pneumothorax; hemothorax; neurological disorders in children; cardiac tamponade; pseudoaneurysm; pediatric oncology practice.

Conflict of interest. The authors declare no conflict of interest.

Introduction

Central venous access is essential in pediatric oncology and hematology, and the frequency of central venous catheterization in this patient population remains high.

The insertion and operation of venous access devices can lead to complications of varying severity, with thrombosis, infections, and pneumothorax or hemothorax being the most common.

Rare but life-threatening complications can also occur during central venous catheterization, and late recognition of these complications can result in patient death [1]. Based on the timing of clinical manifestation, complications are classified as early (detected within 24 hours) and late (detected after 24 hours post-catheterization).

Since 2013, the Dmitry Rogachev NMRC National Medical Research Center of Pediatric Hematology, Oncology and Immunology (NMRC PHOI) has been recording all problems that occur during the insertion of vascular devices. Since 2018, new software has made it possible to analyze these complications. In addition to complications identified since 2018, we have highlighted several rare but relevant complications noted before 2018 or outside the NMRC PHOI.

The aim was to evaluate the potential causes of complications of central venous access insertion in order to develop strategies to prevent complications.

Material and Methods

In 2019–2022, we identified 1512 complications that occurred during 6690 central venous catheterizations in patients aged 1 month to 20 years treated at the Dmitry Rogachev Center.

Ultrasound and C-arm data were recorded during all catheterizations. The catheterization protocol included a complete list of possible complications of catheterization. Timeliness and accuracy of protocol completion were checked daily.

One anesthesiologist was permanently involved in central venous catheterization, and four staff members temporarily replaced him or assisted in catheterization. Training in catheterization (implantation) using ultrasound navigation was conducted semi-annually. Data were collected centrally. An audit was performed. The cumulative risk of all adverse events during venous catheterization and the relative incidence of the most common catheterization complications were calculated. The cumulative risk was defined as the ratio of a given catheterization complication per year to the number of catheterizations per year and expressed as a percentage. Relative incidence was calculated as the ratio of new cases of catheterization complications per year to the estimated rate of catheterizations during the study period and reported as the number of cases per 100 catheterizations per year. The average number of catheterizations per year was calculated as the arithmetic mean of all catheterizations over the 4 years of the audit. The audit results for 2019–2022 are shown in Table 1.

Informed consent for the publication of anonymized observations was obtained from all adult patients or legal representatives of pediatric patients.

A total of 1,512 original observations were included in the analysis. We reviewed 10 complications: failed first venipuncture attempt, guidewire/catheter malposition, guidewire knotting, life-threatening arrhythmias, guidewire entrapment in the trabecular meshwork of the right ventricle, arterial puncture, pneumothorax, hemothorax, puncture of lung parenchyma, and Horner syndrome. In addition, four rare complications were identified: phrenic nerve injury, cardiac tamponade, alveolar hemorrhage, and arterial pseudoaneurysm.

All photographs are from the author's archive.

Complications Related to Insertion of a Central Venous Access Device

Failed insertion on the first attempt. The most common complication of catheterization attempts (8.5 to 11.7% of all catheterizations) was re-puncture. The main reasons included:

— in young children, the similar diameter of the patient's veins and the needle makes it difficult to accurately position the needle in the vein lumen, and when attempting to change the syringe to a J-shaped guide, needle displacement with partial exit of the needle from the vein or puncture of the posterior wall of the vein occurs more frequently;

— insufficient operator proficiency in ultrasound-guided puncture technique (relative incidence rate decreased by 2–3 cases per 100 catheterization-years as operators gained experience).

The significance of the patient's anatomical peculiarities combined with poor proficiency in ultrasound guidance for the risk of iatrogenic complications was confirmed by Vartanova I. V. et al [2].

Malposition of the guidewire or catheter (displacement of the guidewire into the contralateral subclavian or jugular vein, placement of the catheter into the inferior vena cava, or placement of the catheter into the azygos vein). According to our data, the cumulative risk of malposition was 7.7–11.5%. Changes in the direction of guidewire movement could be caused by, among other things, intravascular structures (valves, thrombotic deposits) (Fig. 1, *a*).

Guidewire placement in the unilateral jugular vein during subclavian vein puncture was also frequently observed when the needle entry point was near the jugular-subclavian vein confluence (Fig. 1, *b*).

Anatomical features such as the dilated azygos vein entry site may contribute to incorrect guidewire and catheter positioning.

Fig. 2, a shows a tunneled catheter placed in a 10-year-old patient A. with a history of multiple venous catheterizations and catheter-associated thrombosis. At the time of insertion, no attention was paid to the «tortuous» course of the catheter. The next day, the patient underwent a chest CT, which showed that the catheter was in the azygos vein (Fig. 2, *b*). The catheter was replaced.

Despite the seemingly «harmless» misplacement of the catheter, it should be noted that if the catheter tip is outside the central veins or the right atrium, its location should be considered peripheral, and the administration of irritating

Table. Complications during central venous catheterization in 2019–2022 (data from the Dmitry Rogachev Center).

	v.femoralis	v. jugularis interna	v. subclavia	Total, 2019		v. femoralis	v. jugularis interna	v. subclavia	Total, 2020		v. femoralis	v. jugularis interna	v. subclavia	Total, 2021		v. femoralis	v. jugularis interna	v. subclavia	Total, 2022	
				Number, *N*	CR, %				Number, *N*	CR, %				Number, *N*	CR, %				Number, *N*	CR, %
Air embolism		1		1	0.06				0	0.00			2	2	0.12				0	0.00
Acute arrhythmia			1	1	0.06				0	0.00		2		2	0.12			1	1	0.06
Malposition. including	1	18	117	136	7.76	2	43	108	153	9.54	4	43	153	200	11.51		23	129	152	9.52
Migration of the guidewire into the contralateral subclavian vein		6	32	38	2.17		31	19	50	3.12		26	25	51	2.93		12	21	33	2.07
Migration of the guidewire into the jugular vein	1	7	81	89	5.08		7	87	94	5.86	3	6	125	134	7.71		9	107	116	7.26
Displacement of the catheter into the contralateral subclavian vein		3		3	0.17				0	0.00		8		8	0.46				0	0.00
Insertion of the catheter into the right ventricular cavity			1	1	0.06				0	0.00		2		2	0.12				0	0.00
Incorrect positioning of the catheter		2	3	5	0.29	2	5	2	9	0.56	1	1	3	5	0.29		2	1	3	0.19
Multiple puncture attempts	9	49	147	205	11.70	12	38	106	156	9.73	14	58	116	188	10.82	10	27	98	135	8.45
Bleeding from the puncture site			1	1	0.06		1	1	2	0.12		2	2	4	0.23				0	0.00
Hematoma at the puncture site		2	1	3	0.17			2	2	0.12			2	2	0.12		3	3	6	0.38
Puncture of the homonymous artery with clinically significant bleeding				0	0.00				0	0.00	1			1	0.06				0	0.00
Puncture of the homonymous artery without clinically significant bleeding	5	7	23	35	2.00	7	12	7	26	1.62	4	7	21	32	1.84	1		6	7	0.44
Vascular wall injury with guidewire displacement		3	9	12	0.68	1	2	3	6	0.37		7	12	19	1.09	1	5	5	11	0.69
Catheter extravasation		1	1	2	0.11				0	0.00				0	0.00				0	0.00
Vascular/heart chamber thrombosis	1			1	0.06		1		1	0.06				0	0.00			1	1	0.06
Catheter occlusion not related to thrombosis		1		1	0.06				0	0.00				0	0.00				0	0.00
Pneumothorax		1	2	3	0.17				0	0.00				0	0.00				0	0.00
Nerve plexus injury			1	1	0.06				0	0.00				0	0.00				0	0.00
Pneumomediastinum				0	0.00				0	0.00			1	1	0.06				0	0.00
Total complications				402	22.95				346	21.58				451	25.95				313	19.60
Total catheterizations				1752					1603					1738					1597	

Note. Cumulative risk (CR) values for complications located in areas: femoral vein, internal jugular vein, subclavian vein; *n* — absolute number of patients.

and harmful solutions through it is either limited by the infusion rate or not recommended [3]. In addition, the direction of the catheter tip against the blood flow during fluid therapy inevitably leads to regional slowing of blood flow, which is one of the components of Virchow's triad for the early development of catheter-associated thrombosis.

Because incorrect guidewire placement during catheter insertion using the Seldinger technique results in catheter malposition [4, 5], it is important to timely diagnose this issue. Fluoroscopy during catheterization allows for opportunely visualization of guidewire advancement but increases the radiation exposure for the patient and staff. The use of ultrasound visualization of catheter position, such as the ECHOTIP algorithms available in adult, pediatric, and infant versions (ECHOTIP-PED, NEO-ECHOTIP), serves as an alternative [6–8].

The relative frequency of guidewire (catheter) misplacement decreased by 3 per 100 catheterizations per year after additional hands-on training in the simulation center.

Guidewire knotting. Displacement of part or all of the needle lumen outside the vessel after blood sampling results in an extravascular position of the J-tip, with the operator capable of forcing most of the guidewire into the vasculature (Fig. 3). This complication can result in vein injury, knotting, or guidewire damage, especially during forceful manipulation. In our practice, fluoroscopy revealed guidewire knotting in three patients. In two cases, the knot was disentangled by manipulation under fluoroscopic control. One case, shown in Fig. 4, required surgical access to the subclavian vein and release of the guidewire. Fig. 5 shows the retrieved guidewire with the knot. Deep guidewire

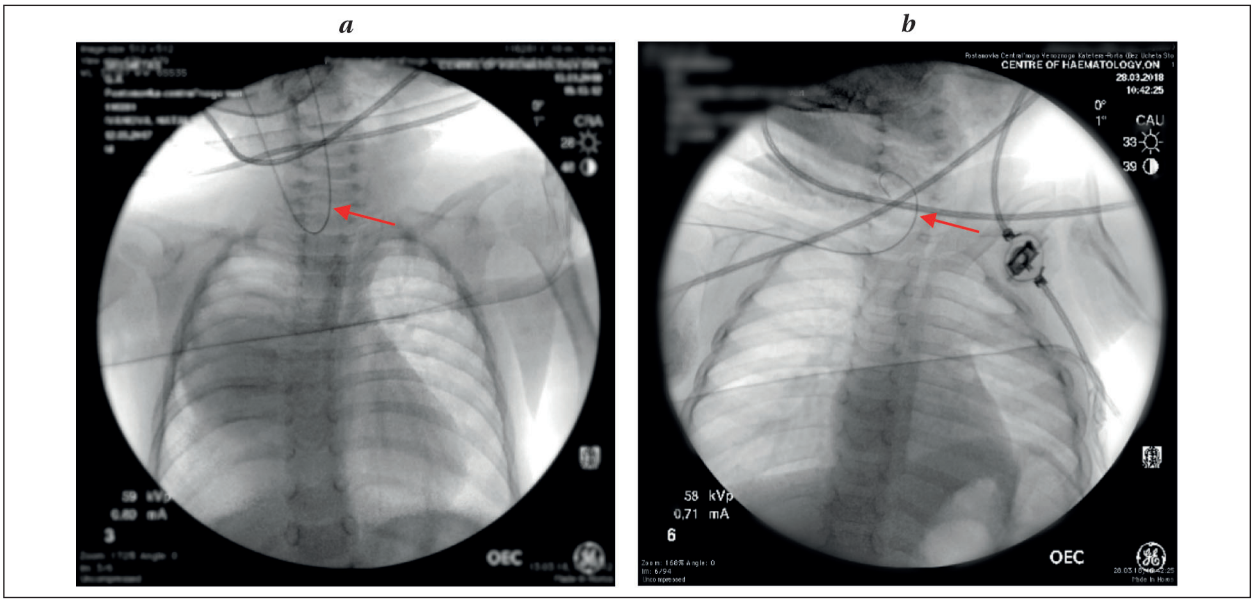

Fig. 1. Change the direction of guidewire advancement.

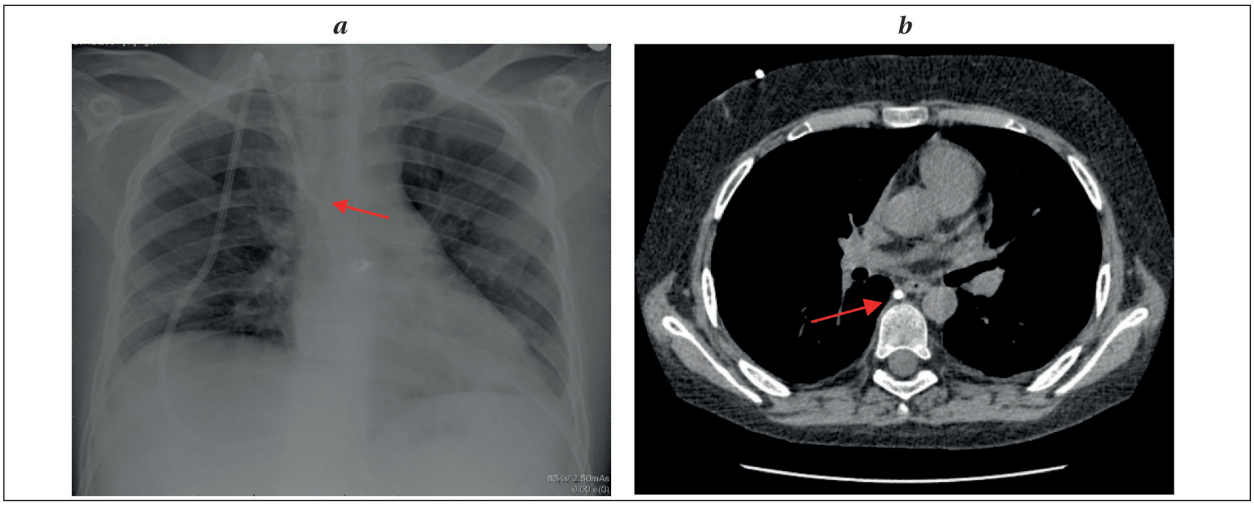

Fig. 2. The catheter placed in the azygos vein (indicated by the arrow).

insertion and rapid guidewire advancement were observed in all three cases.

Life-threatening arrhythmias (ventricular tachycardia, ventricular fibrillation). Introducing the guidewire or catheter too deeply can lead to various complications, including life-threatening ones. In our center, the cumulative risk of acute arrhythmias associated with catheterization was 0.06–0.12%.

Clinical case 1. Patient B., 16 years old, was admitted to the operating room for the placement of a Hickman-type tunnel catheter under sevoflurane inhalation anesthesia. Airway patency was maintained with a second-generation supraglottic airway device. After guidewire insertion and endocardial contact, frequent ventricular extrasystoles developed, progressing to ventricular tachycardia and ventricular fibrillation. Resuscitation, including indirect chest compressions and defibrillation, successfully restored rhythm following the first 150 J discharge.

Guidewire entrapment in the trabecular meshwork of the right ventricle.

Clinical cases 2 and 3. In Patient B., 5 years old, in 2016, and Patient G., 8 years old, in 2018, deep insertion of the guidewire into the right ventricular projection was accompanied by J-tip entrapment (presumably in the myocardial trabeculae). The guidewire could not be withdrawn. Attempts to pull back the guidewire caused it to oscillate in tandem with the heartbeat, and extrasystoles were recorded on the ECG. In both cases, insertion of the catheter through the guidewire and «straightening» of the J-tip of the guidewire in the catheter lumen proved effective, allowing the catheter to be withdrawn to the desired level.

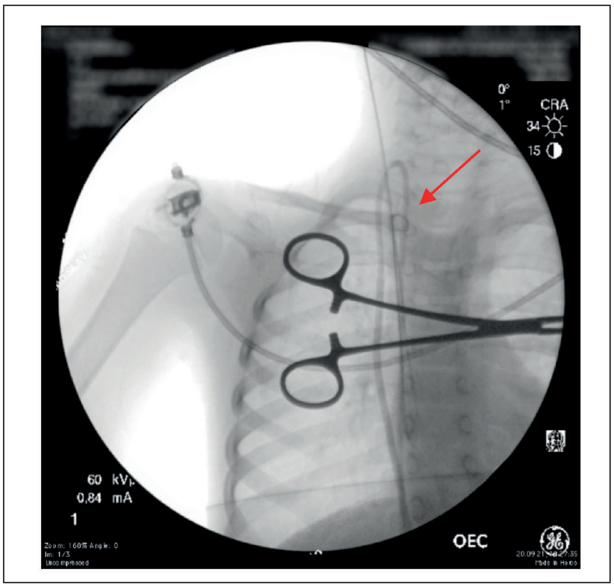

Fig. 3. Extravasation of the J-shaped guidewire (arrow). The guidewire itself is in the venous lumen.

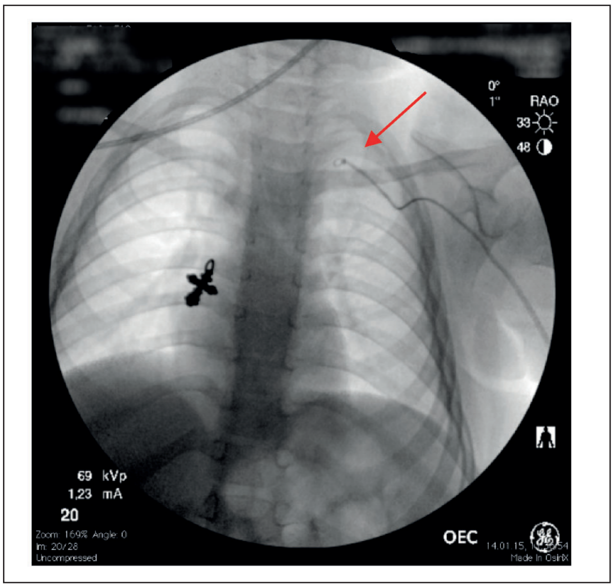

Fig. 4. Knotting of the guidewire in the lumen of the vein (indicated by the arrow).

In 2020, Verma A. et al. reported a similar case in which guidewire retrieval was achieved without additional devices by rotating the guidewire counterclockwise while gently pulling in sync with cardiac contractions [9]. The authors of this report reasonably noted that to avoid complications associated with deep guidewire insertion, it is essential not to insert the guidewire beyond the endpoint of the catheter.

To retrieve the guidewire in such situations, either through the introducer or directly, while preserving the integrity of the flexible catheter tip, Unnikrishan et al. proposed the J-tip straightening technique. This involves pressing the guidewire firmly against the palm with the middle, ring, and little fingers while simultaneously applying force to the guidewire as if «stretching» it with the thumb and index finger of the same hand. This method straightens the J-shaped tip and, as a result, does not require significant force to extract the guide. According to the authors, this method not only avoids complications related to the position of the guidewire, but also preserves the integrity of the J-tip for its eventual reinsertion and prevents vein displacement [10].

If the guidewire and catheter are located in the projection of the right atrium (as seen on x-ray), they may actually be in the inferior vena cava. This misplacement may also be associated with an increased incidence of thrombotic occlusion of the catheter due to the catheter pushing against the blood flow or migration of the catheter into the veins draining into the inferior vena cava. Such a case is shown in Fig. 6. At the time of insertion, the catheter was positioned in the projection of the right atrium. Later, the catheter tip was found to be in the hepatic vein.

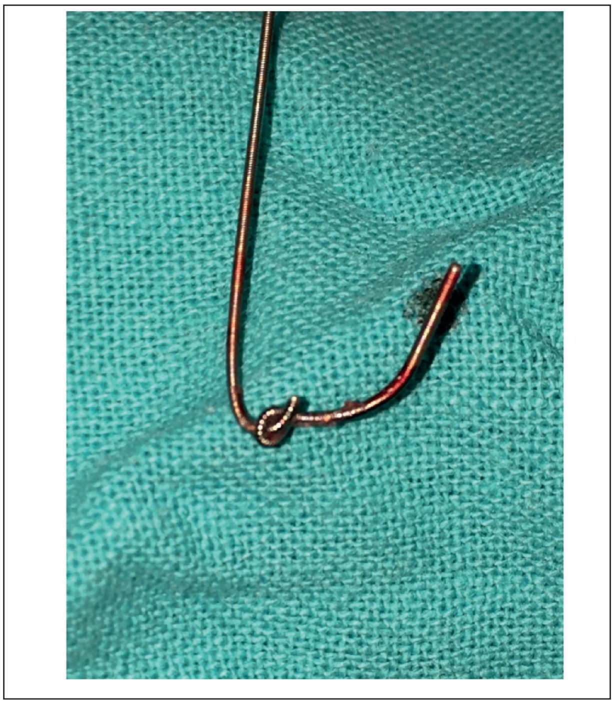

Fig. 5. Knotted guidewire after removal.

To avoid such complications, it is important to follow the rule: «Do not insert the guidewire deeper than the planned catheter location. To control the insertion depth, some guidewire models have markings that indicate both the distance from the catheter tip in centimeters and the length of the guidewire. In the absence of markings, the following method is used. As the needle tip passes the J-tip, the operator's tactile sensation changes. The operator then continues to insert the guidewire, grasping it with the fingers approximately 1 cm from the needle hub. In this way, the approximate depth of guidewire insertion can be estimated and stopped in time, depending on the anatomical characteristics of the patient and the puncture site.

It is also important to remember the dangers of removing the guidewire through the needle or applying excessive physical force to the guidewire. These actions can cause damage and fragmentation (Fig. 7) [11].

Arterial puncture. According to a review [12], the incidence of arterial puncture is 6.3–9.4% during jugular vein catheterization, 3.1–4.9% during subclavian vein catheterization, and 9–15% during femoral vein catheterization. Romanenko N. A. et al. report that the frequency of arterial puncture reaches 3%; the authors attribute this complication to the technique of catheter insertion [13].

In our center, the cumulative risk of inadvertent arterial puncture and catheterization ranged from 0.44% to 2.00%. Arterial puncture occurred more frequently during subclavian vein catheterization, which we believe is due to the significant difficulty of ultrasound guidance. In the absence of ultrasound guidance, inadvertent arterial puncture can be attributed to anatomical variability in the location of arteries and veins in individual patients [14–16]. In addition, when puncturing the subclavian region, the proximity of the skin puncture site to the clavicle causes the needle to pass close to the clavicle. Consequently, as the needle tip is advanced under the clavicle, the bony base acts as a fulcrum, preventing the needle tip from reaching the vein directly. As a result, despite attempts to lower the needle, the needle trajectory becomes more vertical, directing the needle tip toward the artery below the vein (Fig. 8).

Ultrasound navigation may increase the rate of first attempt venipuncture and decrease the rate of inadvertent arterial puncture, but it does not reduce the overall number of complications [17]. The main causes of inadvertent arterial puncture when using ultrasound navigation are poor visualization of the needle tip, which may result from excessive body weight, defects in the imaging technique, and low operator experience.

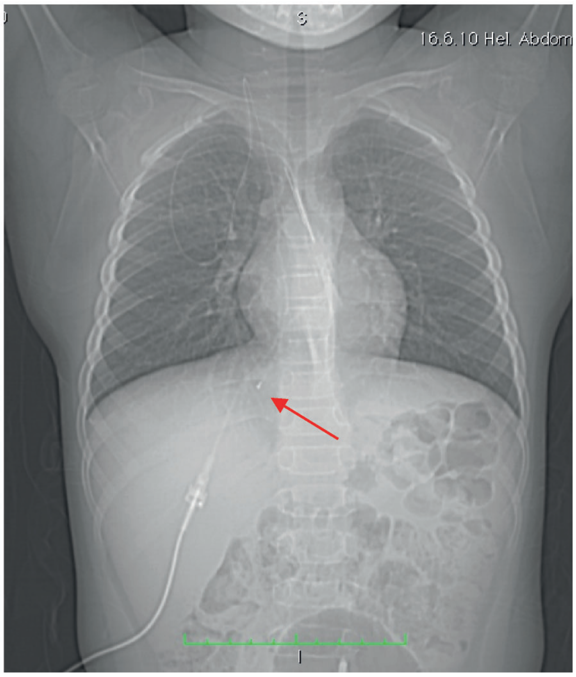

Fig. 6. The tip of the catheter placed in the hepatic vein (indicated by the arrow).

One of the early signs of an arterial puncture is the color of the leaking blood and its pulsatile flow, but these signs may be inconclusive in unstable patients [18]. Radiologic imaging allows detection of the guidewire position on the left side of the vertebral column and may suggest arterial catheterization (Fig. 9).

There was no significant change in the relative incidence of inadvertent punctures (catheterizations). However, by improving the practical skills of ultrasound navigation and training just one staff member in central venous catheterization, this parameter was reduced by 1.5 cases per 100 catheterizations per year.

Another cause of vein wall injury and perforation of adjacent structures, in our opinion, is the attempt to pass a relatively rigid catheter or dilator through the guidewire without properly securing it (Fig. 10).

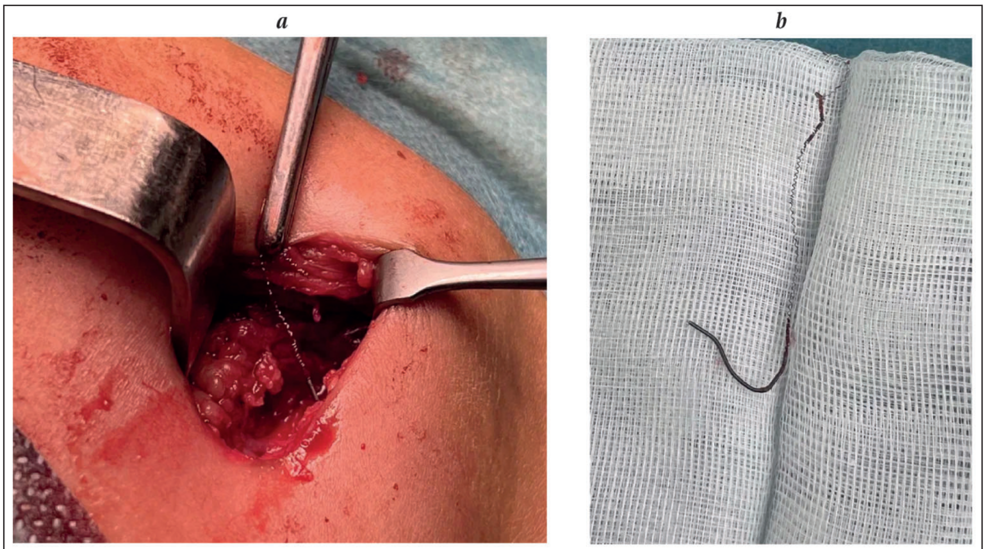

Fig. 7. Guidewire damage: surgical retrieval *(a)* and retrieved guidewire *(b)*.

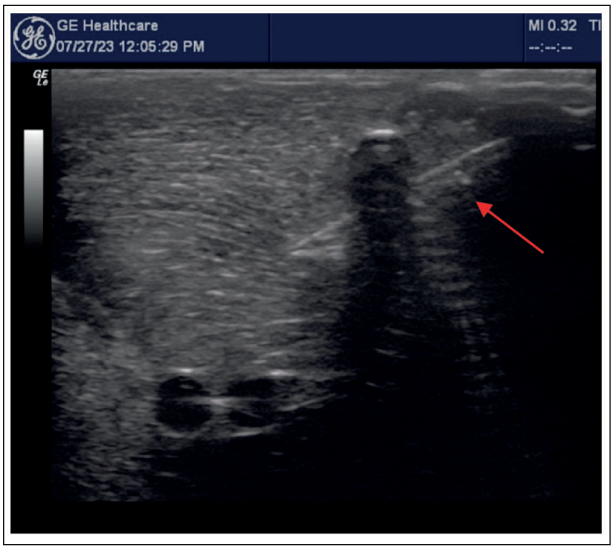

Fig. 8. Needle deflection during puncture through a bony obstruction (simulation) (arrow indicates the needle).

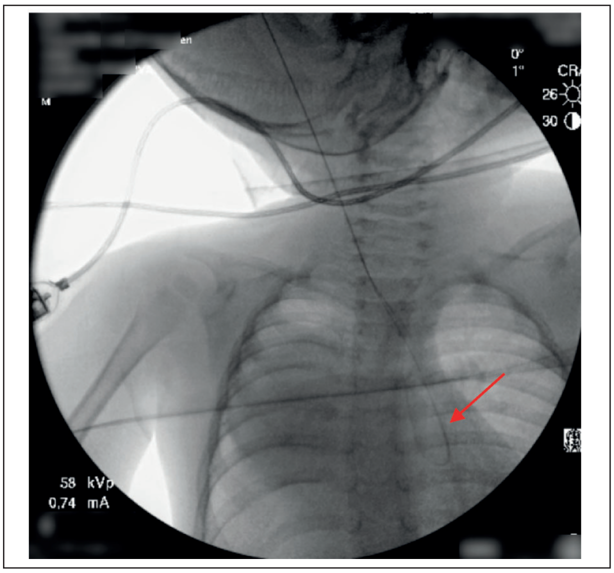

Fig. 9. Arterial puncture; the guidewire (indicated by the arrow) is positioned to the right of the vertebral column.

In this case, the device, which is stiffer than the guidewire, does not slide along the trajectory of the guidewire, but instead moves along its own trajectory, «grabbing» and deforming the guidewire and pulling it behind it. Fig. 10 shows the change in direction of movement of the guidewire and introducer when the outer end of the guidewire is accidentally released.

Similarly, the esophagus was injured during angiography when an introducer was inserted through a guidewire placed in the right internal jugular vein. After contrast injection, the esophageal injury and catheter malposition were confirmed (Fig. 11).

A case of perforation of the internal jugular vein and esophagus during placement of a central line through the left internal jugular vein was also reported in 2020 [19]. According to Wang et al, even deep structures such as the epidural space can be damaged during manipulation with a needle, guidewire, dilator, or catheter, potentially resulting in an epidural hematoma [18].

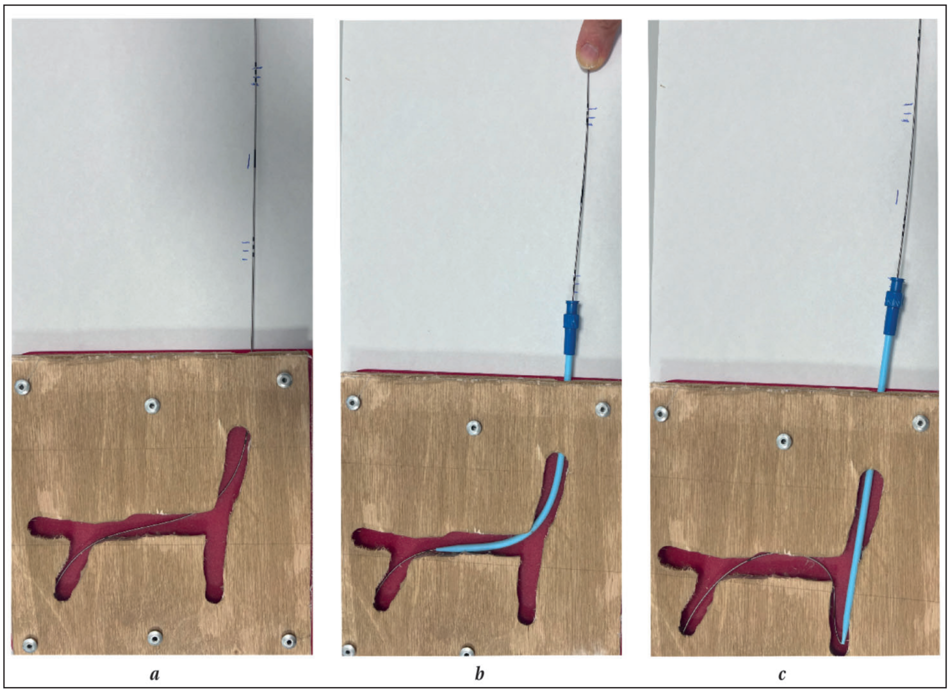

Fig. 10. Change of guidewire direction (simulation).
Note. *a* — the guidewire is inserted into the desired vein (e. g., from the left jugular vein to the superior vena cava); *b* — if the guidewire is held in place (the markings on the guidewire do not move relative to the simulator), the catheter will follow the direction of the guidewire; *c* — if the guidewire is not held in place, the catheter will pull the guidewire behind it due to friction and, with sufficient rigidity, may perforate the vein wall.

Cardiac tamponade. A rare but potentially fatal complication is cardiac tamponade. Because the pericardium merges with the adventitia of the great vessels just above the sternal angle (approximately at the level of the second costo-clavicular junction), perforation of the vein can lead to penetration of the catheter into the pericardium. Such

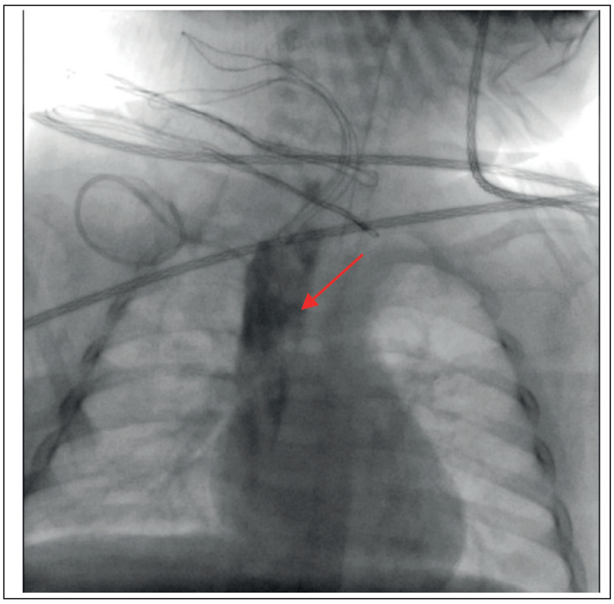

Fig. 11. Perforation of the esophagus by a catheter (contrast medium is visible in the esophagus after the end of its injection). The arrow indicates the esophagus with contrast.

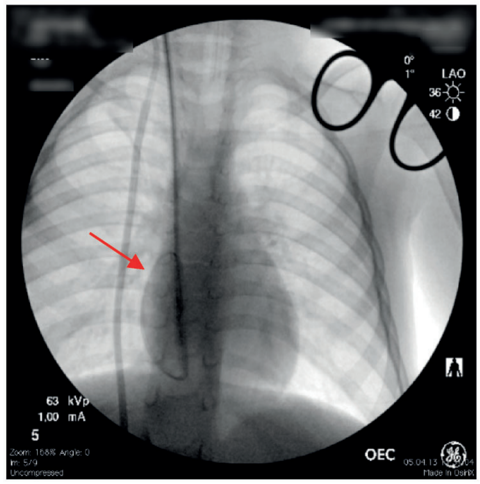

Fig. 12. Guidewire deformation following the shape of the heart.

an injury mechanism usually leads to the «sudden» development of tamponade a few hours after the start of fluid therapy [20].

Another cause of tamponade development is mechanical damage directly to the myocardium, which typically manifests immediately during catheter insertion.

Clinical case 4. Patient D., 2 years old, was admitted to the operating room for tunnel catheterization. A guidewire was inserted into the superior vena cava and its position was confirmed at the junction of the superior vena cava and the right atrium. During insertion of the splittable introducer, the operator did not securely fix the outer end of the guidewire and did not notice the change in its configuration on fluoroscopy (Fig. 12).

After catheter insertion, hypotension to 40/20 mmHg and bradycardia to 30 bpm were observed, and fluoroscopy showed that the borders of the heart were dilated compared to previous images. Chest compressions were initiated and an intraosseous line was placed. Echocardiography revealed hemopericardium with signs of cardiac tamponade. During cardiopulmonary resuscitation, thoracotomy and pericardiotomy were performed, a myocardial defect in the right atrial region was detected, and after suturing, hemodynamic parameters were stabilized. However, the patient continued to have a significant neurological deficit.

Pneumothorax, hemothorax, puncture of lung tissue, alveolar hemorrhage. The anatomic location of the subclavian, jugular, and brachiocephalic veins may increase the risk of damage to the punctured vein and the development of pneumothorax or hemothorax. The subclavian vein, brachiocephalic vein, and superior vena cava are directly adjacent to the pleural cavity (Fig. 13). According to the literature, the incidence of pneumothorax ranges from 0.8 to 3.0% when ultrasound guidance cannot be used [21, 22]. Unfortunately, even the use of ultrasound guidance in the case of loss of needle visualization does not prevent the development of these complications.

When puncturing at the Aubaniac point (1 cm below the border of the inner and middle third of the clavicle), the needle is directed toward the sternoclavicular junction, i.e., puncture is performed in the area of the junction of the subclavian vein with the jugular vein and their transition into the brachiocephalic vein. The apex of the lung is also located in this area, which creates conditions for the development of either pneumothorax and/or alveolar hemorrhage.

Clinical case 5. Patient G., 6 years old. She was admitted to the operating room for the placement of a tunnel catheter. At the time of placement, the guidewire and catheter were positioned in the superior vena cava projection. The operator did not notice their unusual position (Fig. 14). Six hours later, after starting fluid infusion, the attending physician noted decreased breath sounds on the right side of the chest. Control radiography confirmed a right-sided hemothorax (Fig. 15). Aspiration from the catheter produced a pale fluid. After fluid aspiration was stopped, the catheter was removed, and the pleural cavity was drained.

Control radiography in this case was performed after the onset of clinical signs of hydrothorax, because the operator believed that the absence of signs of pneumo- or hydrothorax on intraprocedural radiography was sufficient to exclude this complication.

The main method for timely diagnosis of hydrothorax is chest radiography within 6 hours of

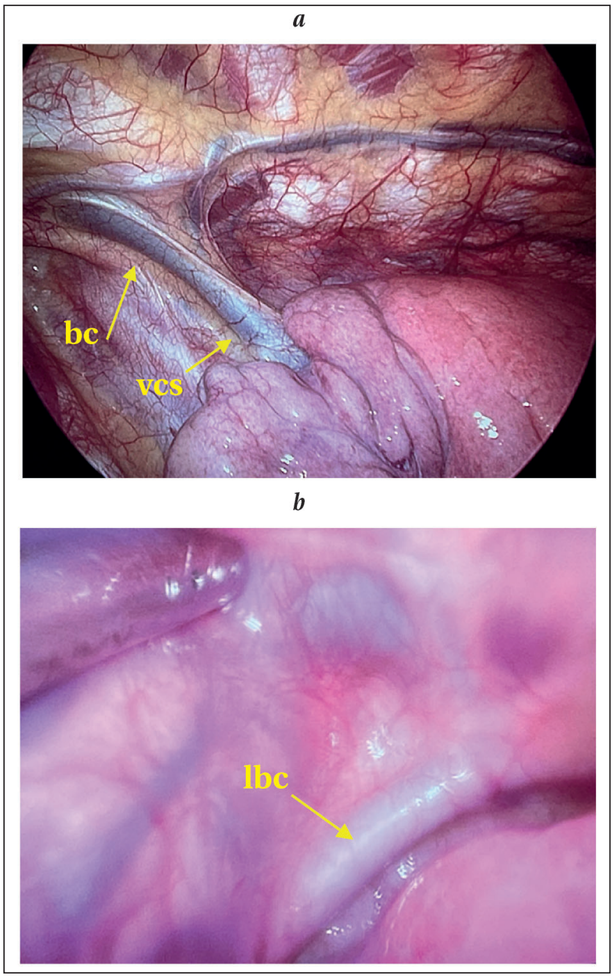

Fig. 13. ***a*** **— right brachiocephalic vein (bc) and vena cava superior (vcs) on thoracoscopy;** ***b*** **— left brachiocephalic vein (lbc) on thoracoscopy.**

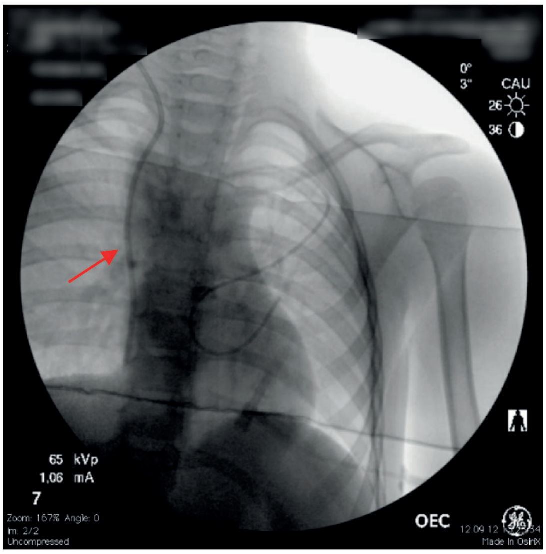

Fig. 14. Catheter in the pleural cavity (indicated by arrow).

Fig. 15. Right-sided hydrothorax.

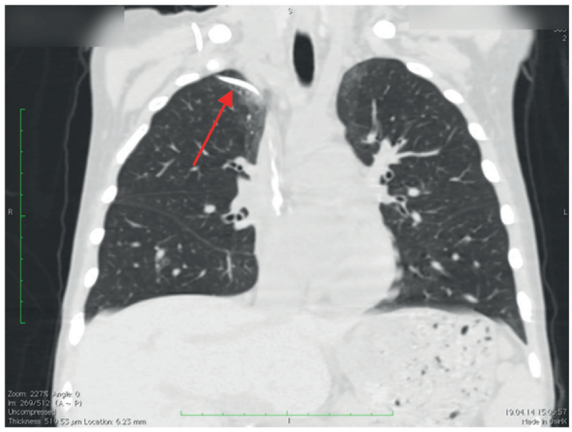

Fig. 16. Catheter passing through lung tissue (indicated by arrow).

catheterization. Ultrasound of the pleural cavity may be used to minimize radiation exposure.

Another option to control catheter position and avoid complications may be to preplan central venous catheterization before routine chest CT. However, this option is primarily applicable to routine catheterization.

Patient Z., 5 years old, was admitted with a catheter previously inserted through the right subclavian vein. Prior to catheter replacement, a chest CT scan was performed, which revealed puncture and catheterization of the upper lobe of the right lung (Fig. 17).

Catheter removal was performed without the expected development of pneumothorax, most likely because the catheter was covered with a fibrin sheath at that time.

Clinical case 6. Patient I., 12 years old, was admitted for surgical treatment. Prior to surgery, a central line was placed through the right subclavian vein. Long-axis ultrasound guidance was used at the time of puncture. Due to difficulty in visualizing the needle, the operator was guided by the movement of the tissue surrounding the needle. Venous puncture and guidewire insertion were successful on the first attempt. Catheter insertion was uneventful. On control radiography, the catheter was located in the superior vena cava region. Thoracoscopy showed that the catheter emerged from the subclavian vein, passed through the lung tissue, and entered the right brachiocephalic vein (Fig. 18). The catheter was removed by the surgeon during thoracoscopy.

In this case, poor visualization of the needle led to compression of the subclavian vein by the needle and unnoticed puncture of both vein walls, followed by further advancement of the needle and puncture of the brachiocephalic vein, from which blood flow was obtained. A catheter was then inserted through the guidewire and advanced through the subclavian vein, pleural cavity, and lung apex tissue into the brachiocephalic vein.

Lung injury may be associated with alveolar hemorrhage, which can be fatal.

Clinical case 7. Patient K., 9 years old, with acute lymphoblastic leukemia. Catheterization of the right subclavian vein was performed using anatomical landmarks without ultrasound. Arterial puncture was successful on the first attempt and venous puncture was successful on the third attempt. After guidewire catheter placement, SpO_2 decreased to 83%. Pleural ultrasound showed no evidence of pneumothorax or hemothorax. At the time of examination, blood was noted in the oral cavity and bradycardia progressed to asystole. Cardiopulmonary resuscitation was initiated with positive results. Tracheal intubation was performed and dark blood was drained from the tracheobronchial tree. Chest radiography revealed bilateral polysegmental infiltration, more pronounced on the right side (Fig. 19). Repeated pleural ultrasonography showed free fluid in the right pleural cavity in the posterior and inferior parts, with separation of the pleural layers up to 6–7 mm and up to 10 mm in the right pleural sinus. Respiratory support was continued. After 7 hours, a second pulmonary hemorrhage occurred, accompanied by hypoxia and bradycardia, leading to cardiac arrest. At autopsy, the lumen of all bronchi was found to be obstructed by blood clots.

The development of alveolar hemorrhage as a result of lung puncture has also been described by Yeldec, Bagchi, Bawa, Goldberg, and Kossaify [22–26]. Yeldec et al. suggested that the main mechanisms include damage to lung tissue or arteries (including both the subclavian artery and the pulmonary artery or their branches) [27]. In cases of isolated lung injury, such complications are usually benign [22]. According to Goldberg et al., when lung injury is associated with arterial injury, a fistula often forms between the blood vessel and the bronchus [25]. In these cases, the outcome can be fatal, especially if the patient has concomitant heart failure, chronic respiratory failure, or coagulopathy [22, 27].

Neurological Disorders Associated with Central Venous Catheterization

Horner's syndrome, characterized by the triad of ptosis, miosis, and enophthalmos, was first de-

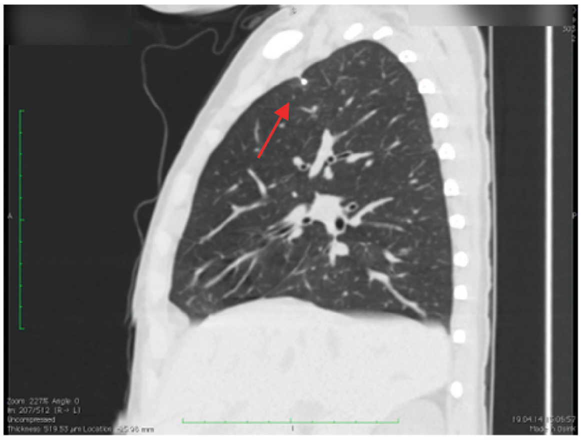

Fig. 17. Catheter passing through lung tissue (indicated by arrow).

Fig. 18. The catheter exits the subclavian vein and enters the brachiocephalic vein after passing through the lung.

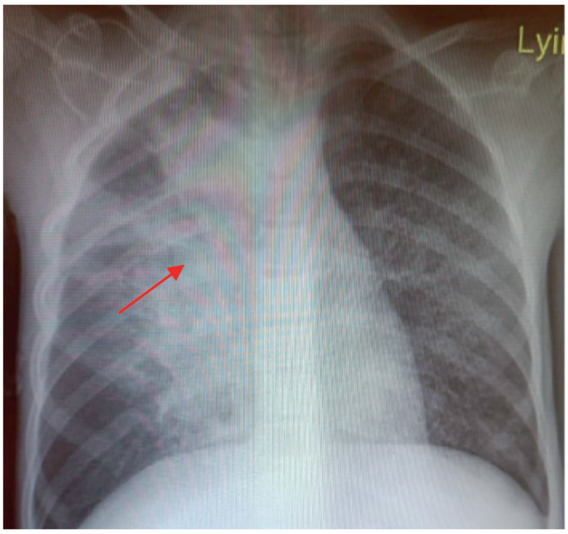

Fig. 19. Infiltration due to pulmonary hemorrhage (indicated by arrow).

scribed by J. F. Horner in 1869. Horner attributed it to impaired sympathetic innervation of the eye [28]. Any disorder affecting the oculosympathetic tract, which consists of three groups of neurons, can cause Horner's syndrome. First-order neurons originate in the posterolateral hypothalamus, pass through the brainstem, and enter the mid-lateral gray column of the spinal cord at the C8–Th1 level. Second-order neurons travel through the apex of the lung into the cervical sympathetic chain near the carotid adventitia. Third-order neurons originate in the upper cervical ganglion, from where they pass through the sheath of the internal carotid artery into the skull, where they divide into the short ciliary nerves (innervating the Müller muscle) and the long ciliary nerves (innervating the pupil dilator) [29].

Clinical case 8. Patient L., 4 years old, underwent the insertion of a tunnel catheter through the left internal jugular vein under ultrasound guidance. During the first catheterization attempt, blood was obtained. Extravasation of the guidewire and the development of a hematoma at the puncture site were observed during the attempt to insert the guidewire. The second catheterization attempt was successful. After 5 hours, ptosis of the left eyelid was noted by the patient's parents (Fig. 20). The patient was examined by an ophthalmologist, and Horner's syndrome was diagnosed. Follow-up continued, and the left-sided ptosis resolved 2 months after catheterization.

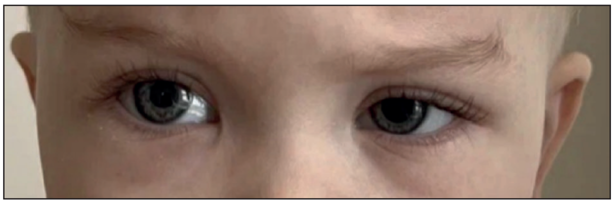

Fig. 20. Horner's sign (ptosis of the left eyelid).

After central vein catheterization, Horner's syndrome may develop as a result of direct damage to the sympathetic circuit, direct damage to the periclavicular nerve tracts, or compression of nerve bundles by a hematoma. Clinical signs can appear within a few hours up to 19 days [30]. Since there is no specific treatment for Horner's syndrome, the primary way to avoid this complication is through prevention.

To this end, several authors have made the following recommendations [29, 30]:

1. Venipuncture should be performed under high-resolution ultrasound guidance. The cervical sympathetic chain can be identified medial to the scalene muscles, lateral to the longus colli muscle, esophagus and trachea, superior to the subclavian artery, and posterior to the pleura and vertebral vessels [31].
2. To avoid puncturing the carotid artery and damaging the sympathetic chain, the needle angulation should not be too steep.
3. The patient's head should be rotated less than 30 degrees.
4. Avoid multiple puncture attempts.
5. If the carotid artery is injured, apply compression to prevent hematoma formation.

Phrenic nerve injury. Depending on its anatomical location, the phrenic nerve can be injured under certain conditions, such as needle insertion, compression by a hematoma or catheter, or nerve block with local anesthesia. The phrenic nerve is formed primarily by the C3–5 roots. It descends along the anterior surface of the anterior scalene muscle, behind the prevertebral fascia, then crosses the subclavian artery behind the subclavian vein and enters the thorax. In some cases, the phrenic nerve may pass through the wall of the subclavian vein. Within the thorax, the nerve contacts the mediastinal pleura all the way to the diaphragm. The right phrenic nerve also contacts the superior vena cava [32].

Clinical case 9. Patient M, 3 years old, was admitted to the operating room for catheterization of the right subclavian vein prior to surgery. The puncture was performed under ultrasound guidance. In the first attempt, the subclavian artery was punctured. On the second attempt, the right subclavian vein was successfully punctured and catheterized. The catheter was placed without difficulty. After 20 hours, the right side of the chest was lagging on physical examination, and auscultation revealed decreased breath sounds on the right side. A control radiograph showed elevation of the right hemidiaphragm, suggesting phrenic nerve paresis on the right side. The phrenic nerve paresis resolved 12 days after catheterization. This transient condition was considered to be the result of compression of the phrenic nerve by a hematoma.

In 2001, a case of right phrenic nerve paresis due to compression through the thin wall of the superior vena cava by a catheter inserted during catheterization of the left subclavian vein was described [33].

In 2017, Bykov M. et al. described a paresis of the vagus nerve located in close proximity to the internal jugular vein. Presumably, the cause of the paresis was a hematoma [34]. Because the mechanism of injury to the phrenic and vagus nerves is the same as that of other nerve trunks, recommendations to reduce the risk of phrenic nerve injury are similar.

Arterial pseudoaneurysm. A pseudoaneurysm is an accumulation of blood that communicates with the arterial lumen but is not surrounded by the arterial wall [35,36]. Iatrogenic pseudoaneurysms occur when the puncture site is not closed and arterial blood is released into the surrounding tissue, forming a pulsatile hematoma. Clinically, they manifest as varying degrees of pain, the formation of a pulsatile hematoma, and the appearance of a mur-

mur or thrill over the hematoma. Untreated pseudoaneurysms may be complicated by rupture, distal embolization, neuropathy, chronic local pain, and local skin ischemia [37, 38].

Clinical case 10. Patient N., 17 years old, was admitted to the operating room for catheterization of the left femoral vein with a 12F catheter under ultrasound guidance for apheresis. The first catheterization attempt resulted in an arterial puncture. Compression of the puncture site was performed for approximately 3 minutes, after which the left femoral vein was successfully catheterized. A 20 cm catheter was inserted into the vein without incident. The next day, 3 hours after apheresis, the catheter was removed. No compression was applied to the puncture site. Four days after catheter placement, the patient complained of pain at the puncture site and noticed an elastic pulsating mass. Ultrasonography revealed a pseudoaneurysm of the right femoral artery (Fig. 21).

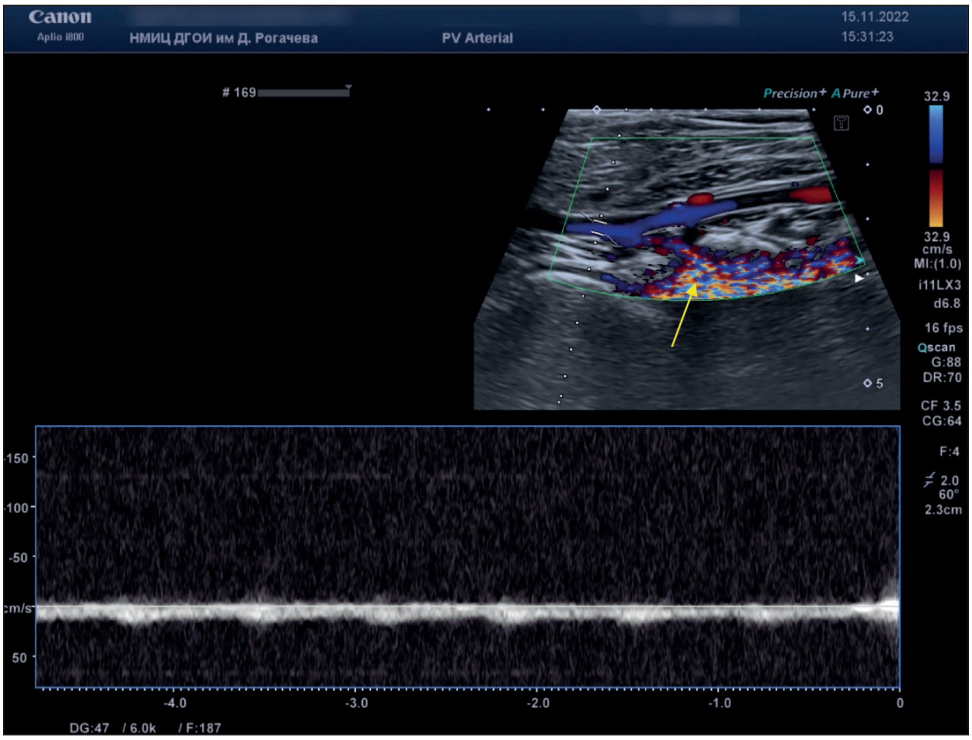

Fig. 21. Pseudoaneurysm of the femoral artery (indicated by the arrow).

A compression bandage was applied for 4 days, after which the clinical manifestations resolved.

Several cases of pseudoaneurysm formation after attempts to puncture and catheterize the veins in the superior vena cava territory have been reported, resulting in brachial plexus paresis. In one case, a carotid artery puncture occurred during an attempt to catheterize the internal jugular vein, resulting in brachial plexus paresis due to compression [39]. In the second case, a pseudoaneurysm developed after puncture of the subclavian artery, also leading to brachial plexus paresis [40].

When treating patients with pseudoaneurysms, open surgical methods, aneurysm compression with or without ultrasound control, and thrombin or collagen injection into the pseudoaneurysm, as well as endovascular stenting, can be used [37–41]. Each of these methods has advantages and disadvantages [38].

A report by Balethbail et al. [42] described the development of thrombosis of a vertebral artery pseudoaneurysm on day 4 after inadvertent puncture of the vertebral artery with a retrieval needle. This patient was not treated because thrombin injection was contraindicated, and surgical intervention was refused by the relatives.

Thus, central venous catheterization remains a procedure with the potential for complications. The use of ultrasound guidance does not currently eliminate the risk of complications, both because of the skill of the operator and the anatomic characteristics of the patient. However, the use of ultrasound guidance and robotic devices that allow automated venipuncture increases the likelihood of successful venipuncture on the first attempt, which helps to reduce the risk of complications [43, 44].

Conclusion

Understanding the causes of various complications of puncture and venous catheterization, including rare ones, allows for timely diagnosis and necessary treatment. A system for recording, controlling, and auditing complications during central venous access placement, as well as improving manual skills and preventing identified causes on simulators in the simulation laboratory, could reduce the incidence of complications related to puncture and venous catheterization.

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