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LAPAROSCOPIC PARTIAL NEPHRECTOMY WITH INTRA-ARTERIAL COLD PERFUSION. WHAT CAN GO WRONG?

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Abstract

Introduction. In kidney masses of a high nephrometric index, a variant of renal ischemia is mostly needed, and to increase the time of compression of the renal artery, the cold renal ischemia may be relevant. Advantages of intra-arterial cold perfusion (IACP) are: good visualization and uniform cooling of the entire thickness of the renal parenchyma. This approach is not without its own set of challenges and potential complications during and after surgery. **Purpose:** to describe complications during kidney resection under IACP and options for their resolution with the practical recommendations based on literature data and clinical cases from our center. **Material and Methods.** The study included 14 patients with kidney masses of a high nephrometric index (RENAL 10 or more), who underwent kidney resections as an experimental technique under IACP from 2021 to 2024 at P.A. Hertzen Moscow Cancer Research Institute. **Results.** We identified both intra- and postoperative complications in 6 cases: perforation of the renal artery (n=1), brachial artery thrombosis (n=1), thrombosis of the renal artery (n=1), air embolism of segmental branches of the renal artery (n=2), urine leakage (n=1). **Conclusion**. The IACP-associated intraoperative complications in our cohort diminished over time as familiarity with the technique improved. The IACP is workable, efficient, and holds promise, indicating its appropriateness for large, well-equipped centers. In patients with just one functioning kidney and high nephrometric index masses needing prolonged ischemia during removal, this technique could become a lifesaving option as expertise grows.

Key words: intra-arterial cold perfusion, cold renal ischemia, kidney resection, partial nephrectomy, high nephrometric index, renal cell carcinoma, intraoperative complications, postoperative complications.

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ЛАПАРОСКОПИЧЕСКАЯ РЕЗЕКЦИЯ ПОЧКИ С ВНУТРИАРТЕРИАЛЬНОЙ ХОЛОДОВОЙ ПЕРФУЗИЕЙ. ЧТО МОЖЕТ ПОЙТИ НЕ ТАК?

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Аннотация

Введение. При выявлении у пациентов образований почки высокого нефрометрического индекса в большинстве случаев необходимо прибегнуть к одному из вариантов ишемии почки, а для увеличения доступного времени пережатия почечной артерии может быть применим метод холодовой ишемии почки. Преимуществами внутриартериальной холодовой перфузии (ВАХП) являются хорошая визуализация и равномерное охлаждение всей толщи почечной паренхимы. Данный метод не лишен недостатков и сложностей, которые могут приводить к интра- и послеоперационным осложнениям. **Цель исследования** – описание возможных осложнений при выполнении резекции почки в условиях ВАХП и вариантов их разрешения с предоставлением практических рекомендаций на основании данных литературы и 14 клинических случаев лечения пациентов в нашем центре. **Материал и методы.** В исследование включены 14 пациентов с образованиями почек высокого нефрометрического индекса (RENAL 10 и более), которым в МНИОИ им. П.А. Герцена за период с 2021 по 2024 г. в качестве экспериментальной методики выполнены резекции почки в условиях ВАХП. **Результаты.** Интра- и послеоперационные осложнения при резекциях почки в условиях ВАХП возникли в 6 случаях: перфорация почечной артерии (n=1), тромбоз плечевой артерии (n=1), тромбоз почечной артерии (n=1), воздушная эмболия сегментарных ветвей почечной артерии (n=2), мочевой затек (n=1). **Заключение.** Частота интраоперационных осложнений, связанных с ВАХП, уменьшилась по мере освоения методики вмешательства. Данная медицинская технология является реализуемой, эффективной и может быть рекомендована к использованию в крупных, технически оснащенных центрах. С набором опыта данная методика может быть вариантом лечения у пациентов с единственной или единственной функционирующей почкой, у которых выявлены образования высокого нефрометрического индекса, требующие длительного времени ишемии при выполнении резекции.

Ключевые слова: внутриартериальная холодовая перфузия, холодовая ишемия почки, резекция почки, высокий нефрометрический индекс, почечно-клеточная карцинома, интраоперационные осложнения, послеоперационные осложнения.

Introduction

Renal cell carcinoma accounts for approximately 3 % of all cancers, with the highest incidence observed in Western countries [1, 2]. The world literature ranks kidney cancer in 14th place, comprising 2.2 % of all malignancies. In 2020, over four hundred thousand new cases of kidney cancer were diagnosed worldwide [3, 4]. The studies show the 60 % rate of localized kidney cancer [5].

The wide coverage of the population by ultrasound and MSCT, easily available diagnostic tools, increases the accidental detection of kidney cancer at the stage of a localized process, urging the organ-preserving treatment. The improvement of technologies allows for its expansion.

Kidney resection allows better preservation of overall renal function compared to nephrectomy, reducing the risk of metabolic or cardiovascular complications. Several retrospective analyses of large databases have shown the correlation of kidney resection compared with nephrectomy with a decrease in cardiovascular mortality and an increase in overall survival, having similar oncological results [6–13]. In patients with pre-existing chronic kidney disease (CKD), kidney resection is the preferred treatment, reducing the risk of further progression of renal failure requiring hemodialysis. Huang et al. found the glomerular filtration rate (GFR) less than 60 ml/min in 26 % of patients with newly diagnosed renal cell carcinoma (RCC), even though normal baseline serum creatinine [14]. Therefore, most scientific associations, such as AUA and EAU, recommend kidney resection as the method of choice for masses available for removal with the possibility of preserving the remaining renal tissue [15, 16].

The kidney is a parenchymal, actively blood-supplied organ, and the resection of the parenchyma involves the choice of an option for creating its ischemia. In modern surgical practice, there are several most common variants of renal parenchymal ischemia. They include thermal ischemia with complete compression of the main trunk of the renal artery and selective thermal ischemia by clamping of the segmental branch of the renal artery leading to the tumor [17]. However, these methods have a time limit not exceeding 30 minutes, according to various studies [18]. Other authors note that time exceeding 30 minutes does not affect kidney function [19]. The preservation of kidney function after resection in localized tumors is of great importance, especially in cases of a single kidney, previous CKD, proteinuria, or multiple/bilateral masses [20, 21]. Currently, most studies report a 10 % decrease in GFR during renal resection under conditions of thermal ischemia in patients with a healthy contralateral kidney [22–24]. This prompted the increase in clinical use of ischemic kidney resection; however, the method is relevant for small peripheral masses not involving massive blood loss [25]. In kidney masses of a high nephrometric index, a variant of renal ischemia is mostly needed, and to increase the time of compression of the renal artery, the cold renal ischemia may be relevant [26]. The proposed mechanism of kidney protection in this approach includes a decrease in cellular metabolism and in the hypoxic damage [27].

In open surgery, cold ischemia has traditionally been performed by covering the organ with ice slush or direct intra-arterial perfusion of the renal parenchyma with a cold solution by cannulating the renal artery [28, 29]. Using cold ischemia in laparoscopic surgery dictates new requirements and stimulates the development of new methods for cooling kidney tissue. Several approaches are known, including cold irrigation, ice slush technique [30], cold ischemia by catheterization of the ureter, and retrograde perfusion of the renal pelvis with a cold solution. However, these methods have several difficulties and limitations, such as ice in the operating field, uneven cooling of the renal parenchyma, a temperature gradient, and prolonged achieving of the target temperature. These shortcomings were partly eliminated by intra-arterial cold perfusion (IACP). IACP does not need to deliver ice to the abdominal cavity through the opening of the trocar, which also complicates visualization in the operating field. It also achieves a uniform cooling of the entire thickness of the renal parenchyma and prevents a cold periphery and warm "core" of the kidney tissue phenomena [31, 32].

It should be mentioned that this approach is not without its own set of challenges and potential complications during and after surgery.

Purpose

The article is aimed at a description of complications during kidney resection under IACP and options for their resolution with the practical recommendations based on literature data and the 14 clinical cases from our center.

Material and Methods

The study group included 14 patients with kidney masses of a high nephrometric index (RENAL 10 or more), who underwent kidney resections as an experimental technique under IACP from 2021 to 2024 at P.A. Hertzen Moscow Cancer Research Institute. The essence of the method is cannulation of the brachial artery with an angiocatheter, introduction of this catheter into the renal artery and perfusion of the renal parenchyma with Ringer's solution cooled to 4 degrees. In this case, the kidney is disconnected from the main blood flow by blocking the blood flow in the renal artery and renal vein. The outflow of the perfusate is carried out through the opened lumen of either the tributaries of the renal vein or directly the renal vein itself. When mastering the technique, it underwent some changes. In the first 7 patients, renal artery occlusion was carried out by inflating the angiocatheter balloon. Subsequently, we abandoned the use of a balloon for occlusion and for this purpose began to use a rubber tourniquet applied to the renal artery.

The study is non-randomized, prospective. The study was approved by the Ethics Committee of the P.A. Herzen Moscow Cancer Research Institute . All patients signed an informed voluntary consent for the study. This work was included in the registry of studies of P.A. Hertzen Moscow Cancer Research Institute. Table 1 shows the perioperative characteristics and functional results of treatment of all patients operated using the IACP technique. The data obtained, in our opinion, indicate satisfactory functional results, and the number of complications is comparable with the frequency of complications when performing kidney resection with warm ischemia. However, complications associated with IACP still occurred at the stage of mastering the technique and understanding the mechanism of their occurrence will help in preventing these complications.

Results

During the development of the technique, we identified both intra- and postoperative complications. Intraoperative complications were associated with the development of the technique and the search for optimal consumables based on literature data and our experience. We reduced the intraoperative complica-

Table 1/Таблица 1

Pre-, intra- and postoperative characteristics of patients

Пред-, интра- и послеоперационные характеристики пациентов

Пациент/ Patient	Возраст, лет/ Age, years	R.E.N.A.L.	СКФ до операции/ Preoperative eGFR	СКФ после операции (3-и сут)/ Postoperative eGFR(3 days)	СКФ после операции (3 мес)/ Postoperative eGFR (3 months)	Потеря СКФ (3 мес)/ Loss eGFR (3 months)	Гистология/ Histology	R1	Время операции (мин)/ Operation time (min)	Время холодовой ишемии (мин)/ Cold ischemia time (min)	Кровопотеря (мл)/ Blood loss (ml)
№ 1 М/M	71	11	67	48	59	–8	СПКР/ccRCC	Нет/No	245	90	100
№ 2 Ж/W	43	10	88	62	78	–10	СПКР/ccRCC	Нет/No	180	50	100
№ 3 М/M	26	11	111	88	113	+2	СПКР/ccRCC	Нет/No	300	60	1000
№ 4 М/M	61	10	111	93	113	+2	СПКР/ccRCC	Да/Yes	240	60	300
№ 5 Ж/W	36	11	60	52	50	–10	Эпителиально–стромальная опухоль/ Epithelial stromal tumor	Нет/No	230	67	200
№ 6 Ж/W	67	10	90	83	87	–3	СПКР/ccRCC	Нет/No	190	40	100
№ 7 М/M	69	10	89	56	82	–7	ХПКР/ Chromophobe renal cell carcinoma	Нет/No	160	50	200
№ 8 Ж/W	51	10	95	88	91	–4	СПКР/ccRCC	Нет/No	170	65	100
№ 9 М/M	67	10	93	65	90	–3	СПКР/ccRCC	Нет/No	230	55	200
№ 10 М/M	58	10	66	46	62	–4	СПКР/ccRCC	Нет/No	155	66	50
№ 11 М/M	36	10	50	11	48	–2	СПКР/ccRCC	Нет/No	195	115	200
№ 12 Ж/W	55	10	66	79	77	+11	АМЛ/AML	Нет/No	165	56	100
№ 13 Ж/W	56	10	59	56	56	–4	СПКР/ccRCC	Нет/No	190	103	200
№ 14 М/M	56	10	87	87	88	+1	СПКР/ccRCC	Нет/No	230	60	500
Среднее/ Mean	53	10,2	80,8	65,2	78,1	–2,7	–	–	205,7	66,9	239,2

Note: created by the authors.

Примечание: таблица составлена авторами.

tions rate to that of kidney resection with classical thermal ischemia.

Perforation of the renal artery

In one case, positioning of a balloon catheter in the lumen of the renal artery was complicated by perforation of its segmental branch by the end of the angiocatheter (Fig. 1, 2).

We used the Cordis POWERFLEX PRO PTA Dilation Catheter 5Fr angiocatheter, which rigid and narrow distal end can mechanically damage the artery wall. The catheter's limitation was the requirement to position the 6-cm filled balloon with an 8-mm diameter as distally as possible in the renal artery, consequently elevating the risk of artery perforation at the site of its division into segmental branches. We used this balloon catheter is seek of a more reliable blocking blood flow in the renal artery but found its non-universality. The catheter's migration towards the aorta during balloon inflation is attributed to the short artery. It is necessary to install the catheter in the distal part of the vessel that can perforate the segmental branches. If the length of the renal artery is over 6 cm, this catheter is safer. Here, the segmental renal artery defect was sutured with a nodular atraumatic suture with a prolene 4.0 thread. Such complications are not described in the literature, since in such studies the authors preferred Fogarty catheters, which have a soft end and a round short balloon (which allows positioning the catheter distantly from the renal artery bifurcation), both reducing the risks of perforation [33].

Based on this case, we recommend always perform the preoperative CT analysis of diameter, extent, and the wall of renal vessels (Fig. 3, 4).

Brachial artery thrombosis

In one case, thrombosis of the brachial artery occurred at the site of its puncture when installing an

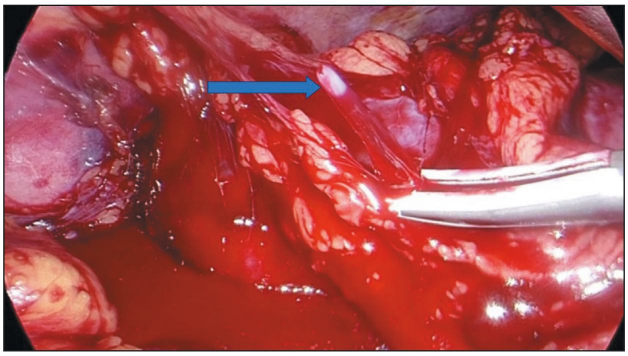

Fig. 1. Intraoperative image of the renal vascular zone on the right. Distal end of the angiocatheter.
Note: created by the authors
Рис. 1. Интраоперационный вид зоны почечных сосудов справа. Дистальный конец сосудистого катетера. Примечание: рисунок выполнен авторами

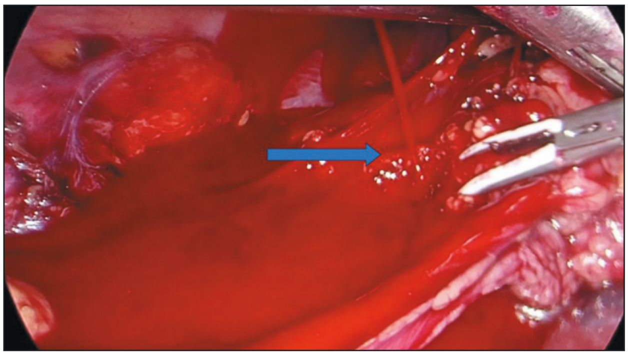

Fig. 2. Intraoperative image of the renal vascular zone on the right. Bleeding from the perforation of the segmental branch of the renal artery. Note: created by the authors
Рис. 2. Интраоперационный вид зоны почечных сосудов справа. Кровотечение из перфоративного отверстия сегментарной ветви почечной артерии.
Примечание: рисунок выполнен авторами

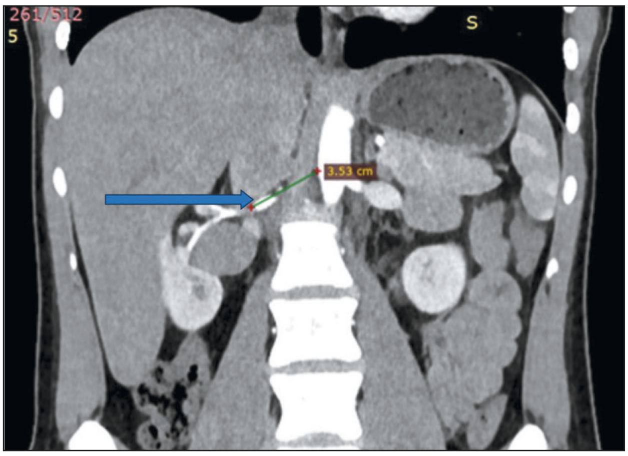

Fig. 3. Preoperative MSCT of abdominal organs with intravenous contrast. The arrow shows the length of the right renal artery.
Note: created by the authors
Рис. 3. Предоперационное МСКТ органов брюшной полости с внутривенным контрастированием. Стрелкой указана длина правой почечной артерии.
Примечание: рисунок выполнен авторами

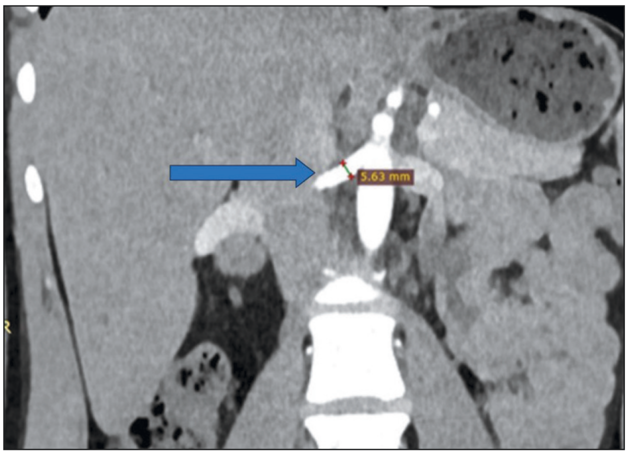

Fig. 4. Preoperative MSCT of abdominal organs with intravenous contrast. The arrow shows the diameter of the right renal artery.
Note: created by the authors
Рис. 4. Предоперационное МСКТ органов брюшной полости с внутривенным контрастированием. Стрелкой указан диаметр правой почечной артерии.
Примечание: рисунок выполнен авторами

introducer to insert a catheter into the renal artery. Cannulation of the left brachial artery was complicated by cyanosis of the skin below the puncture site on the left arm. Pulse oximetry showed no pulse wave, and the hand was cold to the touch. Ultrasound was performed with vascular dopplerography. Luminal thrombosis was found at the site of the cannulation of the brachial artery wall. The thrombi were removed with a Fogarty catheter through the left radial artery access. Thrombosis was probably associated with multiple attempts to puncture the narrow artery (2.5 mm). The complications faded during the mastering of the technique and accumulating experience with small diameter arteries. We recommend preoperative MSCT to measure the brachial artery diameter and select an appropriate catheter, especially in subtle patients (Fig. 5).

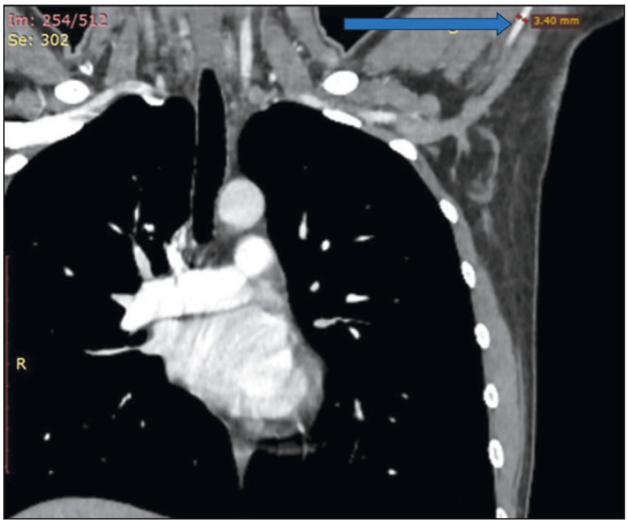

Fig. 5. Preoperative chest MSCT with intravenous contrast. The arrow shows the diameter of the left brachial artery. Note: created by the authors
Рис. 5. Предоперационное МСКТ органов грудной клетки с внутривенным контрастированием. Стрелкой указан диаметр левой плечевой артерии.
Примечание: рисунок выполнен авторами

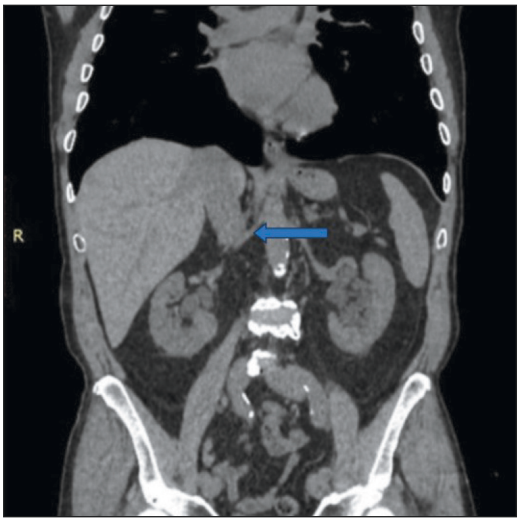

Fig. 6. Preoperative MSCT of abdominal organs with intravenous contrast. The native phase. The arrow shows the right renal artery. Absence of atherosclerotic plaques in the renal artery wall. Note: created by the authors
Рис. 6. Предоперационное МСКТ органов брюшной полости с внутривенным контрастированием. Нативная фаза. Стрелкой указана правая почечная артерия. Отсутствие атеросклеротических бляшек в стенке почечной артерии.
Примечание: рисунок выполнен авторами

Thrombosis of the renal artery

One case of kidney resection and evacuation of the balloon catheter from the renal artery complicated with insufficient blood supply and a pale color of the renal parenchyma. Ultrasound with Dopplerography showed no blood flow in the lumen of the renal artery, since the latter was packed with thrombotic masses. We associate this complication with a probable rupture of an atherosclerotic plaque, not detected by the native phase of preoperative MSCT, in the lumen of the renal artery at the time of catheter positioning and balloon inflation. The follow-up MSCT with intravenous contrast on the 3rd day after surgery confirmed a kidney infarction (Fig. 6, 7).

The patient noted minor soreness and a single sub-febrile body temperature rise, corrected by nonsteroidal anti-inflammatory drugs and non-narcotic analgesics. No additional treatment, including surgery, was required. Both IACP technique and classical thermal ischemia with compression of the renal artery with a vascular clamp always make a risk of injury to the artery dictating the necessary assess of the vascular wall condition by MSCT to identify both the presence and the exact location of atherosclerotic plaques. This information allows us to more accurately select the safe area of compression or obstruction of the renal artery.

Air embolism of segmental branches of the renal artery

Literature describes perfusion of the kidney from a container with a cooled solution connected to the angiocatheter through an infusion system and placed 150 cm above the perfused organ to provide a hydrostatic pressure sufficient to overcome capillary resistance [34].

We failed to achieve the required perfusion rate by hydrostatic pressure only and supplied the solution manually under sterile conditions using a 20 ml syringe. Mastering the technique, we noted a case of air bubbles in the segmental arteries on a follow-up abdominal CT scan on the 3rd day after surgery, regarded as an air embolism causing ischemia of the kidney segment supplied by this segmental artery (Fig. 8, 9).

In one case, the air embolism was massive and led to a kidney infarction. In both cases, no additional surgical interventions or drug treatment were

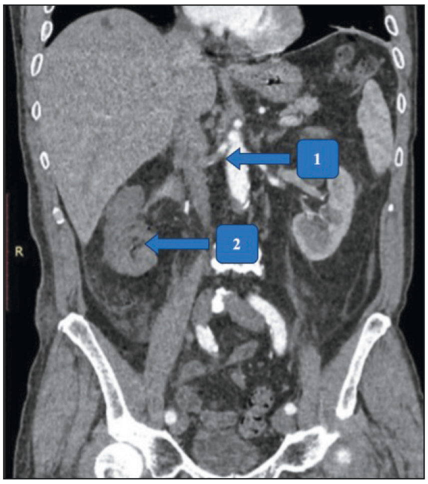

Fig. 7. Abdominal MSCT with intravenous contrast on the 3rd day after the surgery. Notes: 1 – thrombotic masses in the lumen of the right renal artery; 2 – avascularized parenchyma of the right kidney; created by the authors
Рис. 7. МСКТ органов брюшной полости с внутривенным контрастированием на 3-и сут после операции. Примечания: 1 – тромботические массы в просвете правой почечной артерии; 2 – аваскуляризированная паренхима правой почки; рисунок выполнен авторами

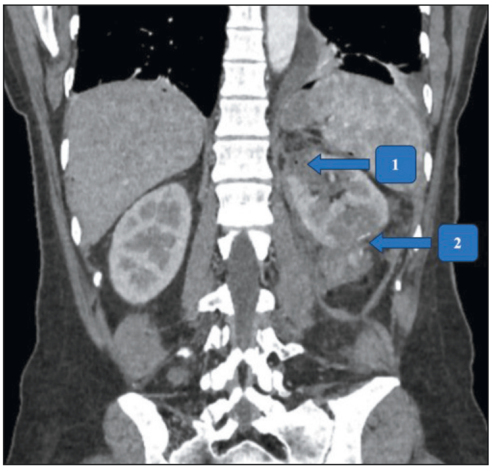

Fig. 8. Abdominal MSCT with intravenous contrast on the 3rd day after surgery, arterial phase. Notes: 1 – air bubble in the artery surrounded by an ischemic area in the parenchyma; 2 – resection area and suture of the renal parenchyma; created by the authors
Рис. 8. МСКТ органов брюшной полости с внутривенным контрастированием на 3-и сут после операции, артериальная фаза. Примечания: 1 – пузырек воздуха в артерии и окружающая его зона ишемизированной паренхимы; 2 – зона резекции и шва паренхимы почки; рисунок выполнен авторами

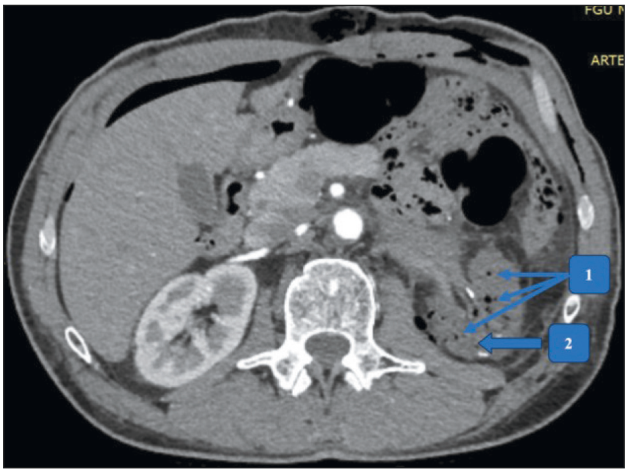

Fig. 9. Abdominal MSCT with intravenous contrast on the 3rd day after surgery, arterial phase. Notes: 1 – air bubbles in the segmental branches of the renal artery; 2 – ischemic renal parenchyma; created by the authors
Рис. 9. МСКТ органов брюшной полости с внутривенным контрастированием на 3-и сут после операции, артериальная фаза. Примечания: 1 – пузырьки воздуха в сегментарных ветвях почечной артерии; 2 – ишемизированная паренхима почки; рисунок выполнен авторами

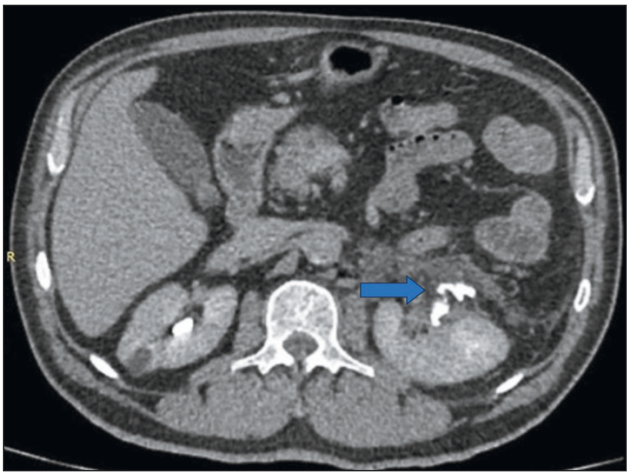

Fig. 10. Abdominal MSCT with intravenous contrast on the 6th day after surgery, excretory phase. The arrow shows the contrast agent entered the perinephric tissue in the renal pelvis region. Note: created by the authors
Рис. 10. МСКТ органов брюшной полости с внутривенным контрастированием на 6-е сут после операции, выделительная фаза. Стрелкой указано, что контрастное вещество попало в паранефральную клетчатку в области лоханки почки. Примечание: рисунок выполнен авторами

required. This experience emphasizes the crucial role of controlling the supply of solution to the perfused organ accurately to prevent the solution from being contaminated with air impurities.

In our sample of patients, postoperative complications above Grade 3 Clavien–Dindo were reported in one case. In one patient, a follow-up CT with intravenous contrast on the 6th day after surgery showed a limited accumulation of up to 50 cubic cm of fluid in the perinephric tissue. In the delayed excretory phase, the contrasted urine entered the perinephric tissue in the pelvis (Fig. 10).

We decided installing an internal ureteral stent for 2 months. On the 10th day after the surgery, low-grade fever and leukocytosis up to 20×10^9/l developed. Reflux pyelonephritis was diagnosed, which required the installation of an urethral catheter and a change of antibacterial therapy.

Table 2/Таблица 2

Summary table of the characteristics of complications in the study group
Сводная таблица характеристики осложнений в исследуемой группе

Пациент/ Patient	Интраоперационные осложнения/ Intraoperative complications	Послеоперационные осложнения выше III степени по Clavien–Dindo, не специфичные для ВХАП/ Postoperative complications higher than grade 3 according to Clavien–Dindo are not specific for IACP	Послеоперационные осложнения выше III степени по Clavien–Dindo, специфичные для ВХАП/ Postoperative complications higher than grade 3 according to Clavien–Dindo specific to IACP	Осложнения, специфичные для ВАХП, не потребовавшие лечения и коррекции/ Complications specific to IACP that did not require treatment and correction
№ 1 М/M	1 – перфорация почечной артерии/ 1 – renal artery perforation	–	–	–
№ 2 Ж/W	–	–	–	1 – тромбоз почечной артерии/ 1 – renal artery thrombosis
№ 3 М/M	–	–	1 – тромбоз плечевой артерии/ 1 – brachial artery thrombosis	–
№ 4 М/M	–	1 – мочевой затек/ 1 – urine leakage	–	–
№ 5 Ж/W	–	–	–	1 – тромбоз сегментарных ветвей почечной артерии/ 1 – thrombosis of segmental branches of the renal artery

Note: created by the authors.

Примечание: таблица составлена авторами.

Otherwise, no complications specific to IACP were detected, however, half of the early postoperative cases presented with subfebrile fever lasting 3–5 days not accompanied by leukocytosis above 14×10^9/l and cured by a change of antibiotic therapy.

Table No. 2 chronologically shows intra- and postoperative complications in accordance with the international Clavien – Dindo classification, which shows that all complications were noted at the stage of mastering the technique, namely in the first 5 patients.

Discussion

While evaluating the complications of our cohort of patients, we searched and analyzed the world literature on the topic. From the PubMed database, 12 articles were selected describing several case series of laparoscopic kidney resection using IACP. The techniques differed having in common laparoscopic access and the supply of a cooled solution into the renal artery isolated from the circulation at the resection stage. IACP showed the high efficiency and the significant advantage over thermal ischemia in terms of GFR preservation in the largest studies by American and Chinese colleagues [35]. Alternatively, kidney resection using cold perfusion caused no significant loss of kidney function compared with the preoperative values [36, 37].

The world literature provided no articles on complications directly related to IACP. The surgical outcomes and complications experienced during and post-surgery were not exclusive to IACP but were instead associated with the results of laparoscopic kidney resection using different ischemia induction techniques, underscoring the significance of the method of inducing ischemia.

Marley et al. faced 2 postoperative complications above Grade 3 Clavien Dindo in a sample of 31 patients who underwent laparoscopic kidney resection under IACP [37]. In one case, bleeding from an emerging arteriovenous fistula was detected on the 13th day after surgery. The patient underwent selective embolization of the segmental branch of the renal artery under X-ray control and a single packed red blood cells transfusion. P. De Backer et al. [33, 38] also described a similar treatment for delayed bleeding as selective embolization, which is a common practice to eliminate such complications.

To prevent this complication, we recommend intraoperative monitoring of the resection zone and targeted coagulation of large vessels, allowing to identify the dehisced lumen during resection. When suturing the renal parenchyma after a previous resection, it is important to include all branches, even those deep within the tumor bed, which may require stitching large segmental branches and causing ischemia in the surrounding area. Control CT scan showed urinary congestion in the perinephric tissue in one patient on the 21st postoperative day. The authors drained the perinephric space for 36 days and used antibiotics.

Other authors have also described similar complications, but used an ureteral stent for draining [36]. In case of intraoperative violation of the integrity of the renal pelvis, we always recommend insert an internal ureteral stent through the defect area. In doubts about the integrity of the pelvicalyceal system in the postoperative period, the discharge is analyzed for creatinine and urea, and their increase several times higher than in blood always prompt endoscopic internal ureteral stent insertion for 2 months. The literature recommends the ureter outflow blocking with a vascular clamp at the stage of kidney mobilization to dilate the pelvicalyceal system by the resection, ensuring its better visualization at the stage of resection [33].

Several authors described cases of bleeding in the early postoperative period urging repeated surgical interventions with the revision of the abdominal cavity and retroperitoneal space [31, 32]. In all cases, the bleeding was caused by the failure of the renal parenchymal suture, which required its re-stitching. To prevent this complication, examine the kidney resection area thoroughly after removing the balloon catheter from the lumen of the renal artery and starting blood flow. The complete filling of the kidney with blood may take some time (up to 2–5 min), urging inspection of the suture area with possible re-stitching. The patient's blood pressure should be maintained at or slightly above the average daily blood pressure. In the vast majority of cases, we cover the resection area by a hemostatic material. This technology achieves hemostasis more reliably and reduces the postoperative bleeding [39].

To prevent postoperative bleeding, we use the hermetic suturing in the perinephric fat tissue. In case of bleeding, it separates the abdominal cavity from the resection zone and helps stop bleeding possibly by forming a hematoma in a small space. In the completed bleeding, its timely detection is the key to a favorable outcome of this complication. Do not neglect the installation of insurance drainage in kidney resection, especially after complex and extensive resections of tumors with a high nephrometric index. This allows a fast detection and conservative or surgical control of postoperative bleeding.

G. Janetschek et al. described a case of rupture of the renal artery during positioning and filling of the balloon in the lumen of the main trunk of the renal artery [31]. After this case, the authors refused to inflate the balloon to block the renal blood flow and installed an angiocatheter to supply a cold solution during resection into the renal artery under X-ray control. He blocked the central blood flow by clamping the renal artery with a loop of a 5 mm tourniquet, covering the angiocatheter and preventing damage to the intima. Atherosclerosis of the renal artery increases the risk of damage to the intima; however, a tourniquet can be installed under visual and tactile control in places free from atherosclerotic plaques, which cannot be achieved when locating the balloon under X-ray control. It is only possible to cognitively compare CT and fluoroscopy during the contrast injection into the angiocatheter balloon. It is also difficult to achieve ideally the required balloon pressure on the artery walls from the inside, enough to block blood flow but not disrupt the integrity of the artery wall and the intima. The risk of artery rupture, as outlined by G. Janetschek et al., is compounded by the potential for significant blood loss during surgery if the balloon is not properly inflated [40].

It is recommended to measure the diameter of the renal artery at the preoperative stage to understand the exact amount of fluid supplied to the angiocatheter balloon sufficient for the renal artery obturation. However, this parameter is variable and depends on the systolic blood pressure and elasticity of the vascular wall. With high blood pressure or high elasticity of the renal artery wall, the pre-planned amount of fluid may be insufficient to block blood flow. The diameter of the balloon can be adjusted by increasing its volume, based on the bleeding from the resection zone of the renal parenchyma. It is difficult to balance the sufficient systemic blood flow block with the avoiding the renal artery damage, and the accurate pressure in the balloon can not be prescribed. The tourniquet can not cause such consequences.

A. Beri et al. described one case of conversion caused by the impossibility of excising an intra-parenchymal tumor [32]. In the absence of a laparoscopic ultrasound device, the author used conversion and a palpatory search for a tumor in the depth of the renal parenchyma, focusing on tactile sensations. A center providing surgery of complex kidney masses, including intra-parenchymal or small tumors, must have all the necessary equipment, including a laparoscopic ultrasound sensor. It helps not only in the search for intrarenal masses but also allows intraoperatively to find a blood clot in the renal vein up to segmental branches, frequent in large kidney masses, and removable using IACP.

P. De Backer et al. described a case of nephrectomy because of ongoing uncontrollable bleeding from the kidney parenchyma suture after starting blood flow in it [33].

We recommend selective stitching of large branches of renal vessels, which can be visualized on the surface of the resected renal parenchyma, followed by covering the resection zone with hemostatic material. IACP does not limit the surgeon by the duration of ischemia. Thus, according to research data, the safe time of renal ischemia using intra-arterial cold perfusion technology can reach 2 hours [41, 42].

This time allows the prevention of complications and precise suturing the segmental branches of the renal vessels and the structures of the pelvicalyceal system, prevents the postoperative bleeding and urinary congestion and fistulas in the early and long-term postoperative period (Fig. 11–13).

F. Li et al. described the difficulties that a surgeon may face during kidney resection in the presence of additional renal arteries [36].

The cessation of blood flow in the main renal artery by inflating the angiocatheter balloon and the supply of cold liquid under constant pressure are insufficient to provide the clean surgical field. Blood flow through the accessory renal arteries still complicates view and can cause a significant blood loss even from a small renal vessel in prolonged resection. Cooling of the renal parenchyma by providing a cold solution through the main trunk of the renal artery reduce the temperature of the entire organ, and clamping additional arteries will not lead to the loss of a large percentage of perfused parenchyma and affect the overall decrease in organ temperature. If the patient has 2 main arteries of equal caliber, it is possible to install 2 balloon angiocatheters for IACP. The branched blood supply to the kidney can be divided mostly into the main trunk and one or more additional arteries. We recommend not to insert several balloon angiocatheters but compress the accessory arteries and catheterize the main trunk of the renal artery (Fig. 14).

A significant number of intra- and postoperative complications were described in the extensive work of

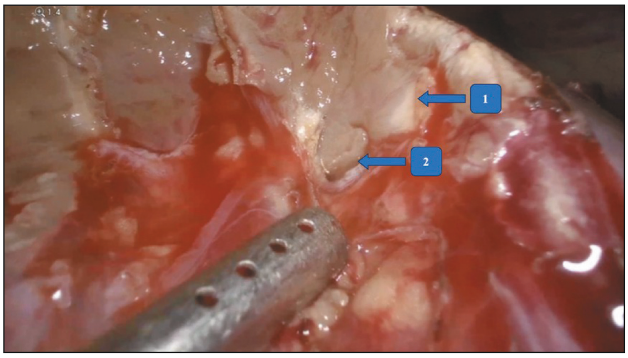

Fig. 11. Intraoperative image of the renal parenchyma resection zone. Notes: 1 – kidney parenchyma; 2 – the gaping lumen of the kidney cup; created by the authors
Рис. 11. Интраоперационный вид зоны резекции паренхимы почки. Примечания: 1 – паренхима почки; 2 – зияющий просвет чашечки почки; рисунок выполнен авторами

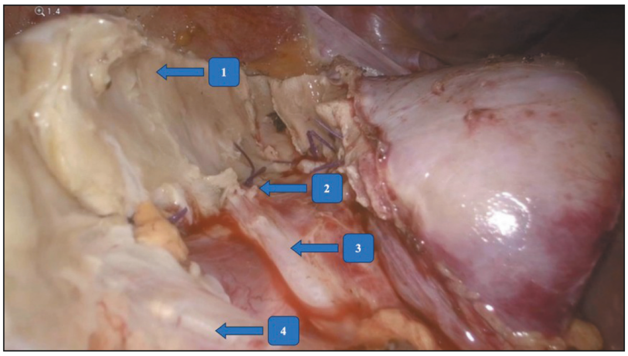

Fig. 12. Intraoperative image of the renal parenchyma resection zone. Notes: 1 – kidney parenchyma; 2 – sutured defects of the pelvicalyceal system; 3 – segmental branch of the renal artery; 4 – the main trunk of the renal artery with an angiocatheter inside; created by the authors
Рис. 12. Интраоперационный вид зоны резекции паренхимы почки. Примечания: 1 – паренхима почки; 2 – ушитые дефекты чашечно-лоханочной системы; 3 – сегментарная ветвь почечной артерии; 4 – основной ствол почечной артерии с ангиокатетером внутри; рисунок выполнен авторами

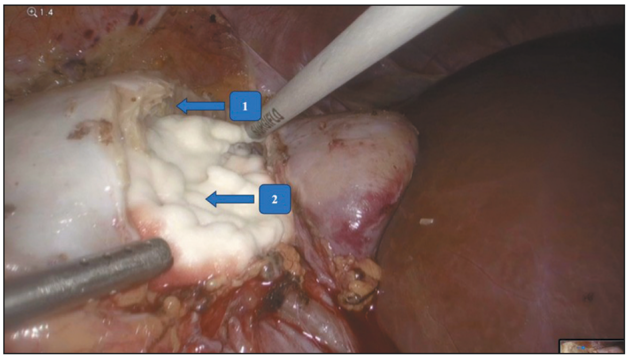

Fig. 13. Intraoperative image of the renal parenchyma resection zone. Notes: 1 – kidney parenchyma; 2 – hemostatic material installed in the tumor bed; created by the authors
Рис. 13. Интраоперационный вид зоны резекции паренхимы почки. Примечания: 1 – паренхима почки; 2 – установленный в ложе опухоли гемостатический материал; рисунок выполнен авторами

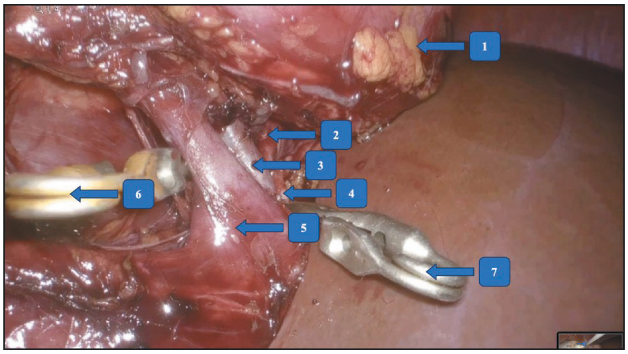

Fig. 14. Intraoperative visualization of the renal vessels on the right before the start of cold perfusion. Notes: 1 – kidney tumor; 2 – the accessory artery No. 1; 3 – the main renal artery; 4 – the accessory artery No. 2; 5 – renal vein; 6 – vascular clamp on the accessory artery No. 1; 7 – vascular clamp on the accessory artery No. 2; created by the authors
Рис. 14. Интраоперационный вид почечных сосудов справа перед холодовой перфузией. Примечания: 1 – опухоль почки; 2 – добавочная артерия № 1; 3 – основная почечная артерия; 4 – добавочная артерия № 2; 5 – почечная вена; 6 – сосудистый зажим на добавочной почечной артерии № 1; 7 – сосудистый зажим на добавочной почечной артерии № 2; рисунок выполнен авторами

German colleagues, which included 65 patients operated using the IACP laparotomy approach [28].

This article proves the advantage of laparoscopic access over laparotomy. We describe 5 cases of postoperative bleeding requiring repeated intervention and 5 cases of urinary fistula development in the early postoperative period. These complications are associated with worse tissue visualization during laparotomy. The laparoscopic approach enables magnification, providing an advantage of controlling the integrity of the pelvicalyceal system and allowing for more precise suturing of the renal parenchyma to prevent bleeding. The article describes the development of acute renal failure, requiring hemodialysis in 5 patients; this is caused by the recruitment of patients with a single kidney and bilateral masses. We observed no patients requiring dialysis after laparoscopic kidney resection; however, in patients with a single kidney and a high nephrometric index (RENAL 11–12), we perform a combined drug therapy for kidney cancer and offer surgical treatment only subsequently, with a decrease in the mass, expecting lower risks of acute kidney injury.

Conclusion

Our experience and the literature data show good functional results of this technique, simplifying technically complex kidney resections (RENAL 10 and more) and preserving kidney function in situations of its disruption when performing resection under thermal ischemia. The assessment of surgical procedures detailed in international publications revealed that the surgical outcomes and complications experienced during and post-surgery were not exclusive to IACP but were instead associated with the results of laparoscopic kidney resection using different ischemia induction techniques, underscoring the significance of the method of inducing ischemia. The IACP-associated intraoperative complications in our cohort diminished over time as familiarity with the technique improved. It verifies that this method is workable, efficient, and holds promise, indicating its appropriateness for large, well-equipped centers. In patients with just one functioning kidney and high nephrometric index masses needing prolonged ischemia during removal, this technique could become a lifesaving option as expertise grows.

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Voluntary informed consent
Written informed voluntaries consents were obtained from the patients for the publication of data and photographs in medical journal.

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