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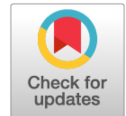

APPLICATION OF AUGMENTED REALITY TECHNOLOGY IN THE SURGICAL TREATMENT OF PATIENTS WITH PRIMARY AND RECURRENT PELVIC TUMORS

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ABSTRACT. Surgical treatment of locally spread tumors of pelvic organs remains an urgent and complicated oncological problem. The recurrence rate after radical treatment ranges from 15.1% to 45.2%. The key to a successful and safe surgical intervention is careful planning and intraoperative navigation, including the use of augmented reality technology. The study presents the experience in the clinical testing of augmented reality technology in the surgical treatment of 11 patients. The paper also described the main stages of the algorithm. Radical operations with intraoperative application of augmented reality technology were performed in eight patients with favorable outcomes. One patient underwent palliative intervention, and two patients did not undergo surgery. In the eight patients who underwent surgery, the median operation time was 202.5 (117.5–282.5) min, the median volume of blood loss was 300 (187.5–625) mL, and the median duration of hospital stay was 21 (17.75––27.75) days. Three patients (37.55%) developed complications, namely, necrosis of the perineal edges of the wound, ascending pyelonephritis, and intrahospital pneumonia. No hospital fatality has been registered. In the postoperative morphological examination, a negative peripheral resection boundary (R0 resection) was achieved in all patients. Subsequently, these patients were referred for dynamic monitoring and systemic antitumor therapy. The application of an augmented reality algorithm in the surgical treatment of primary and recurrent pelvic tumors is feasible and reproducible in clinical practice. Augmented reality technology, with its innovative nature and obvious advantages, opens up certain prospects for improving the results of multivisceral resections of pelvic organs; however, further study and implementation in clinical practice are necessary.

Keywords: augmented reality; combined surgeries; locally spread tumors; preoperative planning; recurrent tumors; pelvic evisceration; radical surgery; palliative therapy.

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ОПЫТ ПРИМЕНЕНИЯ ТЕХНОЛОГИИ ДОПОЛНЕННОЙ РЕАЛЬНОСТИ В ХИРУРГИЧЕСКОМ ЛЕЧЕНИИ БОЛЬНЫХ ПЕРВИЧНЫМИ И РЕЦИДИВНЫМИ ОПУХОЛЯМИ ОРГАНОВ МАЛОГО ТАЗА

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Резюме. Хирургическое лечение местнораспространенных опухолей органов малого таза остается актуальной и сложной онкологической проблемой. Частота рецидивов после радикального лечения составляет 15,1–45,2%. Залогом успешного и безопасного хирургического вмешательства является тщательное планирование и интраоперационная навигация, в том числе с применением технологии дополненной реальности. Представлен опыт клинической апробации алгоритма применения технологии дополненной реальности в хирургическом лечении 11 пациентов. Описаны основные этапы алгоритма. У 8 пациентов выполнены радикальные операции с интраоперационным применением технологии дополненной реальности с благоприятным исходом. Одному пациенту выполнено паллиативное вмешательство, 2 больных не оперировались. У 8 прооперированных пациентов медиана продолжительности операции составила 202,5 (117,5; 282,5) мин, медиана объема кровопотери — 300 (187,5; 625) мл, медиана длительности пребывания в стационаре — 21 (17,75; 27,75) день. Осложнения развились у 3 (37,55%) пациентов и включали некроз краев промежностей раны, восходящий пиелонефрит и внутригоспитальную пневмонию. Госпитальной летальности не зарегистрировано. У всех пациентов по данным послеоперационного морфологического исследования достигнута негативная периферическая граница резекции (R0-резекция). В последующем эти пациенты направлены для проведения динамического наблюдения и проведения системной противоопухолевой терапии. Апробация алгоритма применения технологии дополненной реальности в хирургическом лечении больных первичными и рецидивными опухолями органов малого таза показала его доступность и воспроизводимость в клинической практике. В целом технология дополненной реальности, обладая инновационным характером и очевидными преимуществами, открывает определенные перспективы улучшения результатов мультивисцеральных резекций органов малого таза и требует дальнейшего изучения и внедрения в клиническую практику.

Ключевые слова: дополненная реальность; комбинированные операции; местнораспространенные опухоли; предоперационное планирование; рецидивные опухоли; эвисцерация малого таза; радикальная операция; паллиативная терапия.

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INTRODUCTION

Over the past decade, an incidence of pelvic cancer is steadily growing in Russia. In cancer morbidity structure, 26% are neoplasms of the rectum, bladder, ovaries, vagina, body, and cervix [1]. According to various authors, about 18–32% of newly diagnosed pelvic cancers are locally advanced ones, which is often the reason for refusal to perform a radical surgery and prescribe palliative therapy with a total life expectancy of 1 to 6 months [2–4].

Recent advances in diagnostics and surgical techniques and complex neoadjuvant chemoradiotherapy allow performing combined R0-resections in case of massive tumor invasion into pelvic organs and anatomical structures. In case of recurrent pelvic tumors (RPT), incidence of radical resections is 54–66% [5–8]. Although incidence of local recurrences after such surgeries is 15.1–45.2%, and the overall 5-year survival rate ranges from 23 to 75% and depends largely on the morphological structure of the tumor [5, 9].

It is important to thoroughly assess patients to be able to remove a malignant neoplasm within healthy tissues with neighboring organs and anatomical structures involved. Careful planning is a key condition for a successful and safe surgery. It should be based on analysis of patient imaging with detailed preoperative planning of the surgery scope and its modeling [6, 10].

Augmented reality (AR) technology can be used in surgeries as a modern imaging and navigation tool representing the synthesis of digital data (often visual ones) with real world objects using special technical devices such as augmented reality glasses [11, 12]. In clinical practice, AR has been used since 1980s. Earlier, it started to be used in teaching how to work with complex engineering equipment. The current clinical function of AR is characterized by switch from a training and preoperative planning tool to an intraoperative navigation tool [13]. When used in pelvic tumor surgery, AR technology become one of IT-tools used in clinical practice, along with software products for predicting the course of diseases [14].

There are some foreign publications on the use of AR technology during the preoperative preparation in cardiac surgery, urology, neurosurgery, and oral surgery. There are some reports on using AR in colorectal cancer surgery including recurrent tumors [15–18]. However, the scientific community actively discuss the effectiveness of existing ways of AR application and the availability of digital intraoperative imaging of various tumors, which are not currently reliably proven [18].

Therefore, AR technology is suitable for using in surgery for locally advanced primary and recurrent pelvic tumors due to opportunities for preoperative planning and intraoperative use, and this issue requires further clinical research.

The aim of the study was to evaluate possibilities of using AR technology in the surgical treatment of patients with locally advanced primary and recurrent pelvic tumors.

OBJECTIVES OF THE STUDY

1. Develop and test an algorithm for using AR technology in modeling surgery in patients with locally advanced primary and recurrent pelvic tumors.
2. Assess feasibility of intraoperative use of AR technology in the treatment of patients with locally advanced abdominal and pelvic tumors.

MATERIALS AND METHODS

The study was conducted in the Naval Surgery Clinic of the S.M. Kirov Military Medical Academy and the Coloproctology Department of the I.I. Dzhanelidze Research Institute of Emergency Medicine (RIEM). A step-by-step algorithm was developed for using AR technology in the surgical treatment of patients with locally advanced primary and recurrent pelvic tumors and was tested in all included patients.

As for medical and technical issues, the study used an AR hardware and software system (AR HSS), including a personal computer and AR Microsoft Hololens II glasses, as well as an invasive fixation system developed at the Department of Naval Surgery, used as an X-ray contrast label and a special marker of attachment point for intraoperative integration of a virtual image [13,18]. The matched topographic anatomical model (MTAM) of the patient was constructed by a multidisciplinary team by segmenting preoperative computed tomography (CT) data in the 3D Slicer open-source software.

The clinical part of the study included 11 patients hospitalized at the Department of Naval Surgery Clinic and the Coloproctology Department of the RIEM from November 2021 to August 2022. All patients were divided into two groups. The first group included 5 patients with locally advanced primary pelvic tumors. The second one included 6 patients with established RPTs (Tables 1, 2).

In the total cohort, 6 patients were males (54.54%) and 5 patients were females (45.45%). Median age of patients was 49 (44.25; 55,50). All patients underwent a full preoperative examination in accordance with the national guidelines for pelvic cancer treatment. In all cases, locally advanced primary and recurrent pelvic cancer was established, including histologically. As an additional diagnostic tool, pelvic CT angiography with a fixed radiopaque marker was used.

Median values are provided with 25th and 75th percentiles.

RESULTS AND DISCUSSION

To standardize the approach and unify the technique of using AR in surgery, specialists of the Department of Naval Surgery developed and tested an algorithm that includes 5 successive stages (Fig. 1).

In the study, the full algorithm was followed in 8 (72.72%) patients (full application of AR HSS). In 3 (27.27%) cases,

a shortened version of AR HSS was used because hip invasion of tumor in 1 patient and distant unresectable metastases in 2 patients prevented radical surgery and intraoperative AR application.

Based on experience of using AR technology in neurosurgery [18], it was determined that for an accurate comparison of the virtual model with the intraoperative picture, the following conditions are necessary: the structures included in the MTAM shall be static, located in a relatively closed space with dense walls, and a change in the position of the body has a minimal effect on the relative position of structures of surgical interest. In most cases, locally advanced primary and recurrent pelvic tumors have the above characteristics, which makes it possible to use AR technology in surgical treatment of this category of patients.

For fixing the radiopaque marker and performing CT angiography, an invasive fixation system developed by Department of Naval Surgery was used, including a titanium threaded pin, which was implanted percutaneously in the anterior superior iliac spine. The pin has the necessary contrast, is immovably fixed in bone structures, and is used to fix the marker [13], which provides MTAM during surgery (Fig. 2).

After the pin implantation, a pelvic CT scan was performed with intravenous contrast.

At the next stage, one of the main tasks was to create an anatomically accurate, personalized, visually accessible,

Table 1. Clinical characteristics of the patients in the first group
Таблица 1. Клиническая характеристика пациентов первой группы

Patient	Sex	Age	Source organ	TNM
1	Female	62	Ovary	T3cN0M1
2	Female	42	Cervix	T3bN0M0
3	Male	55	Bladder	T4aN2M1
4	Male	57	Rectum	T4bN1M0
5	Male	45	Bladder	T4bN3M0

Table 2. Clinical characteristics of the patients in the second group
Таблица 2. Клиническая характеристика пациентов второй группы

Patient	Sex	Age	Source organ	Scope of primary surgery	TNM
1	Male	53	Rectum	Abdominoperineal resection	T3cN1aM0
2	Male	67	Rectum	Abdominoperineal resection	T3N1aM0
3	Female	43	Cervix	Total hysterectomy	T1bN0M0
4	Female	46	Cervix	Total hysterectomy	T2aN1M0
5	Male	52	Bladder	Cystectomy	T4aN1M0
6	Female	42	Body of uterus	Hysterectomy	T2aN0M0

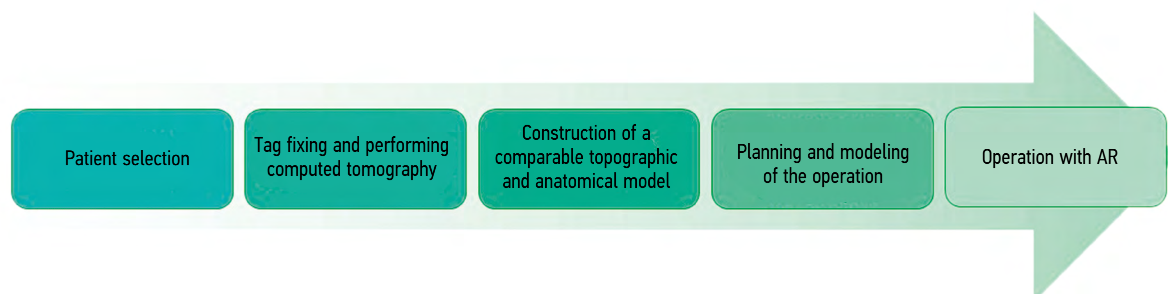

Fig. 1. Algorithm using augmented reality technology in surgery
Рис. 1. Алгоритм применения технологии AR в хирургии

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virtual three-dimensional image such as MTAM. The model was constructed in 3D Slicer open-source software by a multidisciplinary team consisting of a surgeon, an oncologist, a radiologist, related specialists (urologist, gynecologist, a vascular surgeon, neurosurgeon), as well as a process engineer (Table 3). MRI data were used for a detailed assessment and clarification of the local spread of pelvic cancer.

Successive actions of each team member resulted in a three-dimensional model representing the bone structures of the pelvis, bladder, uterus and its appendages, ureters, main vessels (aorta, inferior vena cava, iliac vessels, external and internal iliac vessels, and their tributaries), and a malignant tumor. The organs and structures involved were segmented separately. For more convenient visual perception, each MTAM element was highlighted with its own color. Planes of organ

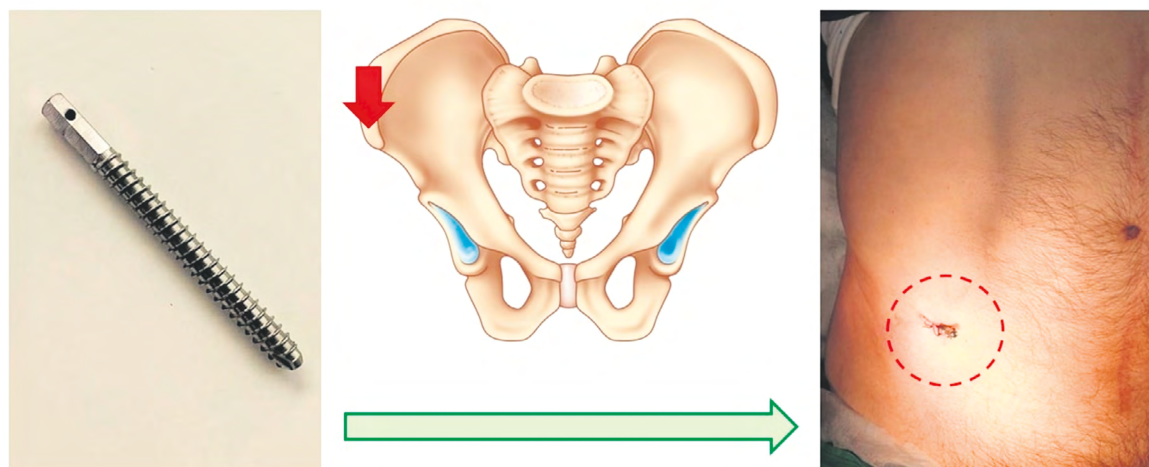

Fig. 2. Scheme of the implantation of the invasive fixation system in the anterior superior spine of the ilium
Рис. 2. Схема имплантации системы инвазивной фиксации в переднюю верхнюю ость подвздошной кости

Table 3. Stages of construction of a comparable topographic–anatomical model by a multidisciplinary team
Таблица 3. Этапы построения СТАМ мультидистциплинарной командой

Multidisciplinary team			
surgeon, oncologist	**radiologist**	**process engineer**	**related specialists (urologist, gynecologist, vascular surgeon)**
Stages of construction			
Formulating a diagnosis	Clarifying a diagnosis according to the CT scan presented	Defining the main anatomical structures	Supplementing a diagnosis
Clarifying the anatomy of surgical area (past operations/treatment)	Labelling anatomical structures on CT images	Constructing a model of organs and tumors	Adjusting the model constructed
Presenting the planned scope of surgery	Identifying problem areas (growth into bone/vascular/nerve structures and adjacent organs)	Labelling sites of tumor involvement with vessels, nerves, and organs	Determining the optimal scope of surgery
Clarifying the main anatomical elements in the model	Identifying sites of tumor involvement with vessels, nerves, and adjacent organs	Constructing a virtual dissection area	Assessing possibility of reconstructive stage
Assessing possibility and scope of a one-time recovery stage	Focusing the attention of specialists on the variant anatomy of the patient	Constructing additional anatomical structures designated by related specialists	Supplementing the MTAM

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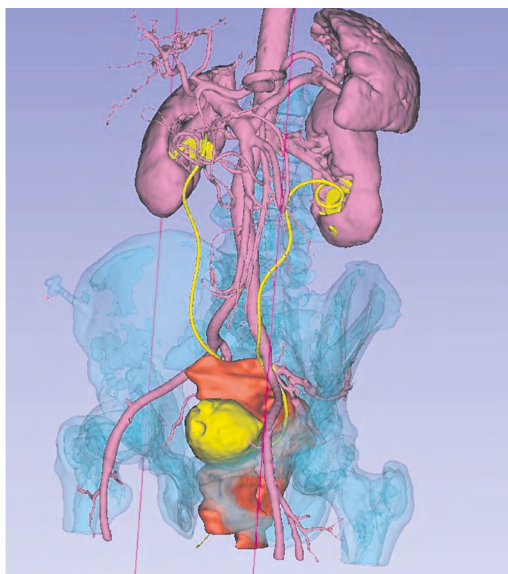

Fig. 3. View of a comparable topographic–anatomical model of a locally advancing rectal tumor (red)
Рис. 3. Вид СТАМ местнораспространенной опухоли прямой кишки (обозначена красным)

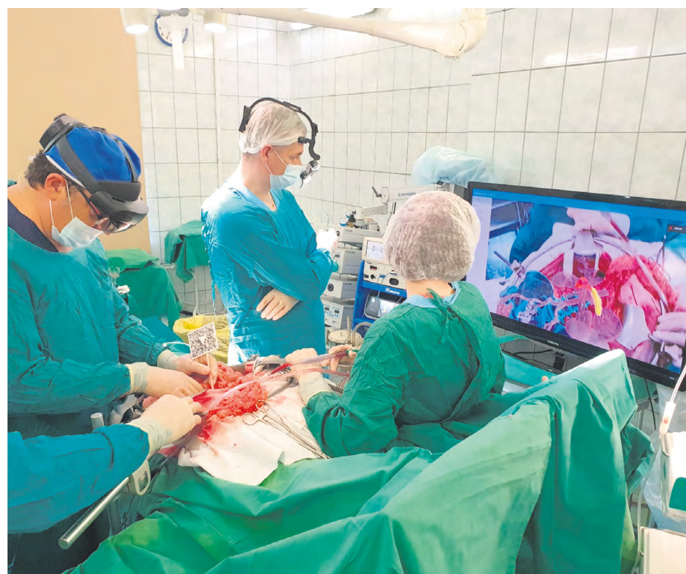

Fig. 4. Stage of intraoperative navigation using augmented reality
Рис. 4. Этап интраоперационной навигации с использованием AR

invasion were labelled separately, as well as sites of proposed vessel ligation, levels of ureter resection, and boundaries of the planned optimal resection plane (Fig. 3).

Each patient included received a multidisciplinary consultation for modeling and scoping the surgery. The consultation was provided by a surgeon, an oncologist, a radiologist, and related specialists. Urologists, gynecologists, and vascular surgeons were invited, if necessary. In 2 cases, a neurosurgeon and a trauma surgeon were consulted to determine the optimal margin for sacral resection. During the consultation, all participating specialists had access to the MTAM of the discussed patient and all medical documentation required.

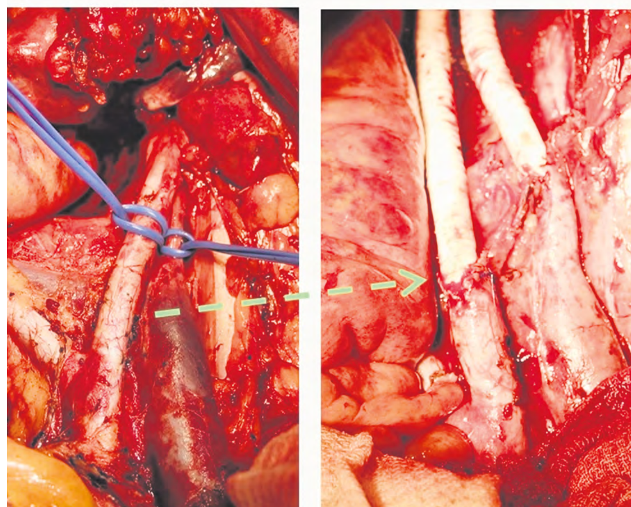

Fig. 5. Stage of resection and prosthetics of the external iliac artery and vein
Рис. 5. Этап резекции и протезирования наружной подвздошной артерии и вены

All surgeries with intraoperative use of AR technology were performed under general combined anesthesia. After a median laparotomy and revision, a special marker was fixed to the pin installed in the iliac crest. The operating surgeon performed intraoperative navigation using Microsoft Hololens II AR glasses. Special software loaded the virtual image onto the monitor of the AR goggles, simultaneously matching it with the marker and positioning it to the operating field. The image was also displayed on the monitor screen for the operating team for clarifying the surgery plan (Fig. 4).

Navigation helped to clarify boundaries of optimal resection area of the tumor, ligation of the main vessels, levels of organ intersection, levels of ureter resection, and other anatomical structures. Median glass work time was 18.5 min (14.5; 27.75).

To establish standard and unified local tumor spread patterns, RPTs were assessed using an original classification developed by the Department of Naval Surgery. This classification was based on 8 anatomical sections of the pelvic cavity: anterior superior, anterior inferior, inferior, central, posterior superior, posterior inferior, lateral left, and lateral right ones. Each section consisted of the corresponding pelvic organs and anatomical structures. In all 6 clinical cases, the recurrent tumor involved more than one compartment (median: 3, min: 2, max: 6). Posterior superior localization of the tumor (sacrum above SII) was not reported in the presented sample (Table 4).

All patients had more than one anatomical structure involved (min: 2, max: 7). Incidence of tumor involvement for various organs and anatomical structures is presented in Table 5.

In Group 1, three surgeries were performed: combined supra-levator total pelvic exenteration, combined posterior

Table 4. Localization of ROOMT in various parts of the pelvis
Таблица 4. Локализация рецидивов опухолей органов малого таза в различных отделах малого таза

Pelvic	Number	Percentage
Anterior superior	3	14.29
Anterior inferior	5	23.81
Inferior	3	14.29
Central	4	19.05
Posterior superior	0	0
Posterior inferior	2	9.52
Lateral left	2	9.52
Lateral right	2	9.52

Table 5. Frequency of organs and anatomical structures of the pelvis involved in the tumor process
Таблица 5. Частота вовлеченных в опухолевый процесс органов и анатомических структур малого таза

Organs and anatomical structures	Number	Percentage
Bladder	6	14.29
Ureter	4	9.52
Prostate, seminal vesicles	2	4.76
Vagina (vagina stump), uterus with appendages	3	7.14
Rectum (rectum stump)	4	9.52
Sacrum below SII, coccyx	2	4.76
Muscles (scar) of the perineum	2	4.76
Anterior abdominal wall	2	4.76
Internal iliac artery	5	11.90
External iliac artery	3	7.14
Bone structures of the pelvic wall	2	4.76
Other*	7	16.67

Note: * — small intestine, parietal and visceral peritoneum, greater omentum, spleen, hip joint, iliac bones.

supra-levator pelvic evisceration with resection and prosthesis of right external iliac artery and vein (Fig. 5), combined resection of the bladder.

In one patient, radical surgery was canceled due to extensive tumor invasion into pelvic bone structures involving the hip joint. In another case, radical surgery was canceled due to distant unresectable metastases.

In Group 2, 5 radical surgeries were performed as follows: 2 combined infra-levator total pelvic evisceration with distal sacrumectomy, 1 supra-levator total pelvic evisceration, 2 combined anterior pelvic evisceration. One patient had palliative colostomy due to the rapid tumor progression, distant unresectable metastases, and intestinal obstruction.

In 8 operated patients, the median surgery duration was 202.5 (117.5; 282.5) min, the median volume of blood loss was 300 (187.5; 625) mL, the median length of hospital stay was 21 (17.75; 27, 75) days. Three (37.55%) patients had complications including necrosis of perineal wound edges, ascending pyelonephritis, and hospital-acquired pneumonia. No hospital mortality was reported. A postoperative morphological testing showed that a negative peripheral resection margin (R0-resection) was achieved in all patients. Subsequently, these patients were referred for dynamic monitoring and systemic anticancer therapy.

Therefore, AR technology with AR HSS was used in 11 patients with constructing a MTAM. The clinical situation allowed the intraoperative use of AR technology in 8 (72.72%) patients. In all cases, surgeries were performed as planned (72.72% of the total cohort).

CONCLUSION

Combined surgery for locally advanced pelvic tumors is one of the relevant problems of the modern surgical oncology. Since the pelvic region is one of the most topographically and anatomically complicated areas, such interventions are associated with the high injury rate and related perioperative risks, require achieving a negative margin of surgical resection and have significant technical issues. Therefore, it is necessary to improve the diagnostic and treatment strategy of surgical treatment for this category of patients. In addition to developing new surgical methods and optimizing the intensive care program, a multidisciplinary approach is needed to select treatment strategies and personalize treatment. Many literature reports indicate that innovative imaging technologies such as augmented reality (AR) are promising for development and clinical testing.

Review of reports on the AR use in treatment of 11 patients with locally advanced primary and recurrent pelvic tumors concluded as follows. Firstly, AR technology significantly increases the effectiveness of preoperative diagnostics and a detailed assessment of the locoregional spread of pelvic tumors. Secondly, AR underpins highly efficient surgery planning by a multidisciplinary team and thereby creates a precedent for an inherently innovative surgery simulation technology. Detailed imaging of a locally advanced tumor, determination of points of its fixation to organs and vital pelvic structures allow not only to determine the scope of the upcoming surgery, but also to formulate a sequence of surgical techniques aimed at the safe mobilization of the removed organs in the dissection plane determined during planning, the observance of which with a high degree of reliability will ensure the achievement of a negative peripheral resection margin. Thirdly, the use of advanced imaging technologies allows the surgical team to “interact” with the model developed in multidisciplinary surgery planning. This circumstance has an unconditional psychophysiological justification and largely determines the success of the upcoming intervention.

Therefore, review of the first use of AR showed that this technology is obviously effective in the preoperative period of patients with locally advanced primary and recurrent pelvic tumors. However, as shown by the present study, the potential of intraoperative AR use needs to be further explored. A preliminary review of immediate outcomes of AR-assisted multivisceral resections indicates an increase in their safety. However, it is premature to unequivocally assess the role of intraoperative AR and its contribution to improving immediate surgery outcomes and increasing surgery radicality in patients with locally advanced pelvic tumors. At the same time, it can be reasonably argued that due to innovative nature and the above-mentioned advantages, the AR technology offers obvious prospects for improving outcomes of multivisceral pelvic resections and requires further study and implementation in clinical practice. In this regard, we assume that the priority task is to develop and further improve this technology for modeling combined surgeries in patients with primary and recurrent malignant pelvic tumors.

REFERENSES

1. Sostoyanie onkologicheskoi pomoshchi naseleniyu Rossii v 2021 g. / Kaprin AD, Starinskiy VV, Shakhzadovoi AO, Eds. Moscow: MNIOI im. Gertsena – filial NMITs radiologii; 2022. 239 p. (In Russ.)

2. Jimenez-Rodriguez RM, Yuval JB, Sauve CG, et al. Type of recurrence is associated with disease-free survival after salvage surgery for locally recurrent rectal cancer. *Int J Colorectal Dis.* 2021;36(12):2603–2611. DOI: 10.1007/s00384-021-03998-4

3. Caprino P, Sacchetti F, Tagliaferri L, et al. Use of electrochemotherapy in a combined surgical treatment of local recurrence of rectal cancer. *Journal of Surgical Case Reports.* 2021;(9):jab403. DOI: 10.1093/jscr/rjab403

4. Lyadov VK, Garipov MR, Moskalenko AN, et al. Accelerated recovery protocol in extended combined and single-stage surgery for pelvic cancer. *Creative Surgery and Oncology.* 2021;11(2):125–131. (In Russ.) DOI: 10.24060/2076-3093-2021-11-2-125-131

5. Matsuyama T, Yamauchi S, Masuda T, et al. Treatment and subsequent prognosis in locally recurrent rectal cancer: a multicenter retrospective study of 498 patients. *Int J Colorectal Dis.* 2021;36(6):1243–1250. DOI: 10.1007/s00384-021-03856-3

6. Mirnezami R, Mirnezami A. Multivisceral Resection of Advanced Pelvic Tumors: From Planning to Implementation. *Clin Colon Rectal Surg.* 2020;33(5):268–278. DOI: 10.1055/s-0040-1713744

7. Park YY, Lee J, Han YD, et al. Survival outcomes after isolated local recurrence of rectal cancer and risk analysis affecting its resectability. *J Surg Oncol.* 2020;122(7):1470–1480. DOI: 10.1002/jso.26161

8. Sorrentino L, Belli F, Guaglio M, et al. Prediction of R0/R+ surgery by different classifications for locally recurrent rectal cancer. *Updates Surg.* 2021;73(2):539–545. DOI: 10.1007/s13304-020-00941-0

9. Khvatov AA, Maistrenko NA, Sazonov AA, et al. The possibilities of surgical treatment of patients with reccurences of rectal cancer. *Bulletin of Surgery named after I.I. Grekov.* 2018;177(2):39–45. (In Russ.). DOI: 10.24884/0042-4625-2018-177-2-39-45

10. Lukyanyuk P.P., Surov D.A., Soloviev I.A., et al. Modern approaches to surgical treatment of patients with locally advanced colon tumors complicated by necrosis. *Bulletin of the National Medical and Surgical Center named after N.I. Pirogov.* 2019;14(4):49–52. (In Russ.). DOI: 10.25881/BPNMSC.2020.91.18.010

11. Guerriero L, Quero G, Diana M, et al. Virtual Reality Exploration and Planning for Precision Colorectal Surgery. *Dis Colon Rectum*. 2018;61(6):719–723. DOI: 10.1097/DCR.0000000000001077
12. González Izard S, Sánchez Torres R, Alonso Plaza Ó, et al. Nextmed: Automatic Imaging Segmentation, 3D Reconstruction, and 3D Model Visualization Platform Using Augmented and Virtual Reality. *Sensors (Basel).* 2020;20(10):2962. DOI: 10.3390/s20102962
13. Ivanov VM, Krivtsov AM, Strelkov SV, et al. Practical Application of Augmented. Mixed Reality Technologies in Surgery of Abdominal Cancer Patients. *Journal of Imaging*. 2022;8(7):183. DOI: 10.3390/jimaging8070183
14. Kotiv BN, Budko IA, Ivanov IA, Trosko IU. Artificial intelligence using for medical diagnosis via implementation of expert systems. *Bulletin of the Russian Military Medical Academy*. 2021;(1(73)): 215–224. (In Russ.).
15. Zawy Alsofy S, Nakamura M, Suleiman A, et al. Cerebral Anatomy Detection and Surgical Planning in Patients with Anterior Skull Base Meningiomas Using a Virtual Reality Technique. *J Clin Med.* 2021;10(4):681. DOI: 10.3390/jcm10040681
16. Thomas DJ. Augmented reality in surgery: The Computer-Aided Medicine revolution. *Int J Surg.* 2016;36:25. DOI: 10.1016/j.ijsu.2016.10.003
17. Leuze C, Zoellner A, Schmidt AR, et al. Augmented reality visualization tool for the future of tactical combat casualty care. *J Trauma Acute Care Surg.* 2021;91:S40–S45. DOI: 10.1097/TA.0000000000003263
18. Ivanov VM, Krivtsov AM, Strelkov SV, et al. Intraoperative Use of Mixed Reality Technology in Median Neck and Branchial Cyst Excision. *Future Internet.* 2021;13(8):214. DOI: 10.3390/fi13080214
19. Eckert M, Volmerg JS, Friedrich CM. Augmented Reality in Medicine: Systematic and Bibliographic Review. *JMIR Mhealth Uhealth*. 2019;7(4):e10967. DOI: 10.2196/10967

СПИСОК ЛИТЕРАТУРЫ

1. Состояние онкологической помощи населению России в 2021 г. / под ред. А.Д. Каприна В.В. Старинского А.О. Шахзадовой. Москва: МНИОИ им. Герцена – филиал НМИЦ радиологии, 2022. 239 с.
2. Jimenez-Rodriguez R.M., Yuval J.B., Sauve C.G., et al. Type of recurrence is associated with disease-free survival after salvage surgery for locally recurrent rectal cancer // Int J Colorectal Dis. 2021. Vol. 36, No. 12. P. 2603–2611. DOI: 10.1007/s00384-021-03998-4
3. Caprino P., Sacchetti F., Tagliaferri L., et al. Use of electrochemotherapy in a combined surgical treatment of local recurrence of rectal cancer // Journal of Surgical Case Reports. 2021. No. 9. P. jab403. DOI: 10.1093/jscr/rjab403
4. Лядов В.К., Гарипов М.Р., Москаленко А.Н., и др. Протокол ускоренного выздоровления при выполнении расширенно-комбинированных и одномоментных операций по поводу опухолей органов малого таза // Креативная хирургия и онкология. 2021. Т. 11, № 2. С. 125–131. DOI: 10.24060/2076-3093-2021-11-2-125-131
5. Matsuyama T., Yamauchi S., Masuda T., et al. Treatment and subsequent prognosis in locally recurrent rectal cancer: a multicenter retrospective study of 498 patients // Int J Colorectal Dis. 2021. Vol. 36, No. 6. P. 1243–1250. DOI: 10.1007/s00384-021-03856-3
6. Mirnezami R., Mirnezami A. Multivisceral Resection of Advanced Pelvic Tumors: From Planning to Implementation // Clin Colon Rectal Surg. 2020. Vol. 33, No. 5. P. 268–278. DOI: 10.1055/s-0040-1713744
7. Park Y.Y., Lee J., Han Y.D., et al. Survival outcomes after isolated local recurrence of rectal cancer and risk analysis affecting its resectability // J Surg Oncol. 2020. Vol. 122, No. 7. P. 1470–1480. DOI: 10.1002/jso.26161
8. Sorrentino L., Belli F., Guaglio M., et al. Prediction of R0/R+ surgery by different classifications for locally recurrent rectal cancer // Updates Surg. 2021. Vol. 73, No. 2. P. 539–545. DOI: 10.1007/s13304-020-00941-0
9. Хватов А.А., Майстренко Н.А., Сазонов А.А., и др. Возможности хирургического лечения пациентов с рецидивами рака прямой кишки // Вестник хирургии им. И.И. Грекова. 2018. Т. 177, № 2. С. 39–45. DOI: 10.24884/0042-4625-2018-177-2-39-45
10. Лукьянюк П.П., Суров Д.А., Соловьев И.А., и др. Современные подходы к хирургическому лечению больных местнораспространенными опухолями толстой кишки, осложненными некрозом // Вестник Национального медико-хирургического центра им. Н.И. Пирогова. 2019. Т. 14, № 4. С. 49–52. DOI: 10.25881/BPNMSC.2020.91.18.010
11. Guerriero L., Quero G., Diana M., et al. Virtual Reality Exploration and Planning for Precision Colorectal Surgery // Dis Colon Rectum. 2018. Vol. 61, No. 6. P. 719–723. DOI: 10.1097/DCR.0000000000001077
12. González Izard S., Sánchez Torres R., Alonso Plaza Ó., et al. Nextmed: Automatic Imaging Segmentation, 3D Reconstruction, and 3D Model Visualization Platform Using Augmented and Virtual Reality // Sensors (Basel). 2020. Vol. 20, No. 10. P. 2962. DOI: 10.3390/s20102962
13. Ivanov V.M., Krivtsov A.M., Strelkov S.V., et al. Practical Application of Augmented/Mixed Reality Technologies in Surgery of Abdominal Cancer Patients // Journal of Imaging. 2022. Vol. 8, No. 7. P. 183. DOI: 10.3390/jimaging8070183
14. Котив Б.Н., Будько И.А., Иванов И.А., Тросько И.У. Использование искусственного интеллекта для медицинской диагностики с помощью реализации экспертной ситемы // Вестник Российской военно-медицинской академии. 2021. № 1 (73). С. 215–224. DOI: 10.17816/brmma63657
15. Zawy Alsofy S., Nakamura M., Suleiman A., et al. Cerebral Anatomy Detection and Surgical Planning in Patients with Anterior Skull Base Meningiomas Using a Virtual Reality Technique // J Clin Med. 2021. Vol. 10, No. 4. P. 681. DOI: 10.3390/jcm10040681
16. Thomas D.J. Augmented reality in surgery: The Computer-Aided Medicine revolution // Int J Surg. 2016. No. 36. P. 25. DOI: 10.1016/j.ijsu.2016.10.003
17. Leuze C., Zoellner A., Schmidt A.R., et al. Augmented reality visualization tool for the future of tactical combat casualty

care // J Trauma Acute Care Surg. 2021. No. 91. P. S40–S45. DOI: 10.1097/TA.0000000000003263
18. Ivanov V.M., Krivtsov A.M., Strelkov S.V., et al. Intraoperative Use of Mixed Reality Technology in Median Neck and Branchial Cyst Excision // Future Internet. 2021. Vol. 13, No. 8. P. 214. DOI: 10.3390/fi13080214
19. Eckert M, Volmerg JS, Friedrich CM. Augmented Reality in Medicine: Systematic and Bibliographic Review // JMIR Mhealth Uhealth. 2019. Vol. 7, No. 4. P. e10967. DOI: 10.2196/10967

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