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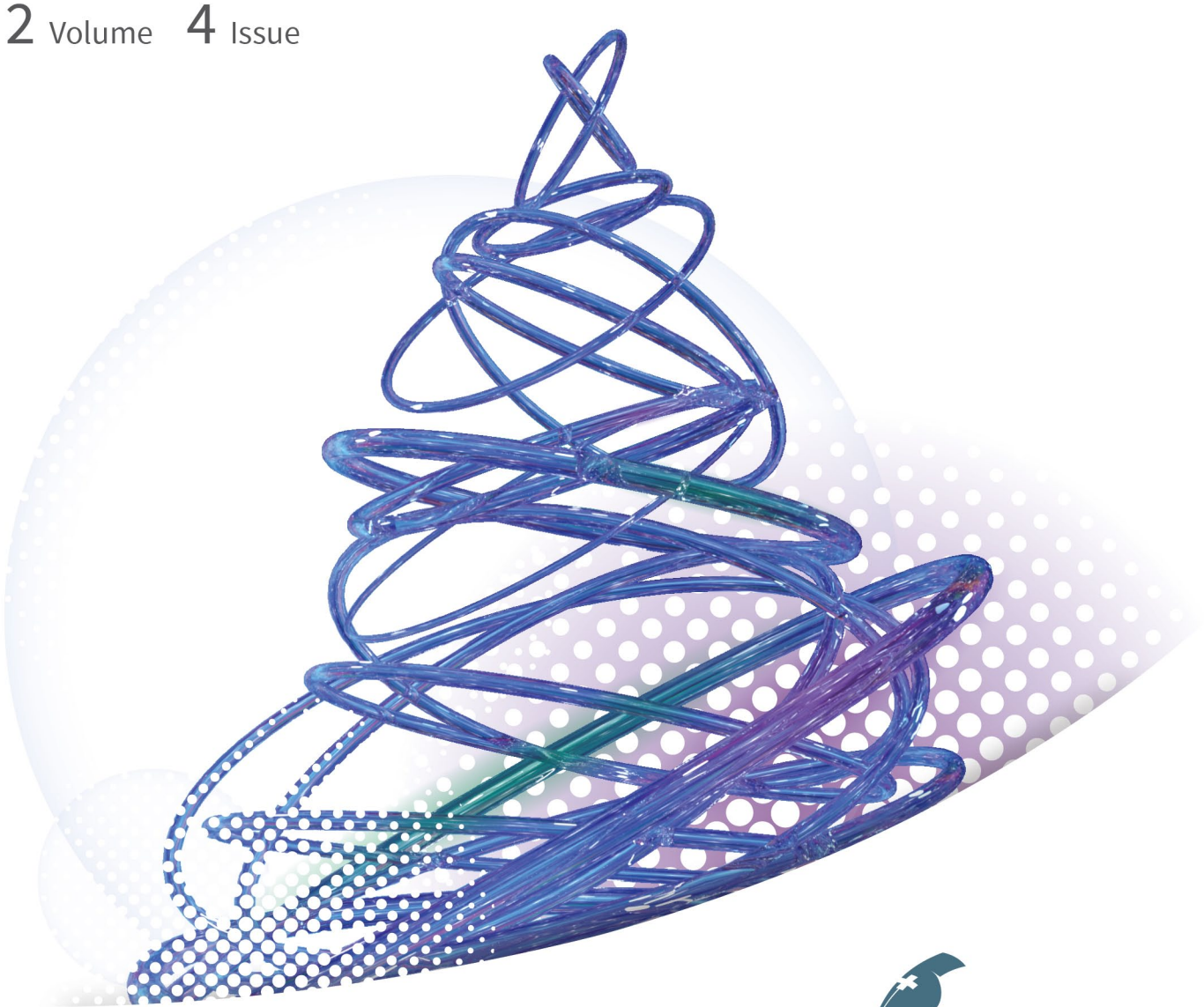

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Путь протяжённостью 25 лет глазами очевидца

Л.А. Низовцова

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АННОТАЦИЯ

Сегодня, в канун 25-летнего юбилея флагмана московской радиологической службы — Научно-практического клинического центра диагностики и телемедицинских технологий Департамента здравоохранения города Москвы (до 2019 г. — Научно-практический центр медицинской радиологии), оживает в памяти яркая четвертьвековая история этого учреждения, пройденные шаг за шагом со дня открытия Центра будни, открытия и торжества.

Вниманию читателей представлена краткая история одного из аспектов многогранной деятельности Центра — развитие профессионального образования специалистов лучевой диагностики. Прослеживается период от становления Центра до признания его авторитета: учебный центр НПКЦ ДиТ ДЗМ в настоящее время привлекается Министерством здравоохранения России в качестве эксперта к участию в решении актуальных задач профессиональной подготовки и аккредитации специалистов лучевой диагностики.

Статья посвящена известным учёным и педагогам, ведущим специалистам профессорско-преподавательского состава, активно участвующим в развитии направления, связанного с повышением квалификации врачей-рентгенологов и других специалистов лучевой диагностики на разных этапах существования Центра. Специалисты учебного центра в своей работе стремятся к соответствию проводимого профессионального обучения положениям Болонского соглашения (1999), созданию условий для получения отечественными специалистами европейских дипломов.

Ключевые слова: профессиональное обучение; даты; личности; Научно-практический клинический центр диагностики и телемедицинских технологий.

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ЭКО•ВЕКТОР

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The 25 years development of the Moscow Center for Diagnostics: through an eyewitness

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Research and Practical Clinical Center for Diagnostics and Telemedicine Technologies, Moscow, Russian Federation

ABSTRACT

Today, on the eve of the 25th anniversary of the leader in the Moscow radiological service, Research and Practical Clinical Center for Diagnostics and Telemedicine Technologies of the Moscow Healthcare Department (used to be the Research and Practical Center of Medical Radiology until 2019), the bright quarter-century history of this institution comes to life in our memory, day after day has passed by since the opening of the Center, our weekdays, scientific breakthroughs, and celebrations.

We would like to present to our readers a brief history of one of the aspects of the Center's complex activities, the development of professional education of radiologists. We observe a period from its launching to its recognition as the authority in radiology. The Education Department of the Moscow Center for Diagnostics and Telemedicine Technologies is currently appointed by the Ministry of Health of the Russian Federation as an expert to participate in addressing the current challenges of professional training and certification in diagnostic radiology.

The article is devoted to well-known scientists and teachers, professors, and leading specialists in the industry, who are actively involved in the development of continuing education of radiologists and other specialists in diagnostic radiology at different stages of the center's existence. Specialists of the Training Center strive for the compliance of the provided professional training following the Bologna Declaration (1999), thereby creating conditions for Russian professionals to obtain European diplomas.

Keywords: professional education; dates; personalities; Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies.

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一个目击者眼中的25年之路

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简评

今天在莫斯科放射服务旗舰——莫斯科卫生部诊断和远程医疗技术科学实用临床中心（至2019年—医学放射科学实用中心）成立25周年前夕—该机构辉煌的四分之一世纪历史，从日常生活、开幕和庆祝中心开幕之日起逐步通过。

向读者简要介绍了该中心多方面活动的一个方面—发展辐射诊断专家的专业教育。从该中心成立到其权威性得到承认的这段时间可以追溯到：SPCC DiT DZM的培训中心目前由俄罗斯卫生部作为专家参与，以解决放射专家专业培训和认证的紧迫问题。

这篇文章致力于知名科学家和教师，教学人员的主要专家，积极参与制定与中心存在不同阶段的放射科医师和其他放射诊断专家的高级培训相关的方向。 培训中心的专家在工作中努力遵守博洛尼亚协议（1999）的规定，并为国内专家获得欧洲文凭创造条件。

关键词：职业培训；日期 性格；诊断和远程医疗技术科学和实用临床中心。

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THE SCIENTIFIC AND PRACTICAL CENTER ESTABLISHMENT

Today, the Center for Diagnostics and Telemedicine has a fairly solid historical foundation, having evolved from the organization in 1976 in the City X-ray Radiological Department (CXRD) in Moscow, which was later transformed into the Diagnostic Center No. 3.

Director of the Scientific and Practical Center for Medical Radiology Professor Yu.V. Varshavsky

In August 1996, Professor Yuri Viktorovich Varshavsky, Director of the Diagnostic Center No. 3, announces to the employees the order of the Moscow City Health Department to rename the institution into the Scientific and Practical Center for Medical Radiology (SPC MR) and the related changes in the main tasks of the Center.

The SPC MR activities significantly expanded the organizational and methodological functions of the CXRD, that was founded and for a long time led by Georgiy Timofeevich Gureev, a long-serving employee of the Moscow X-ray and radiological service with a Ph.D. in Medicine. Professor Viktor Yuryevich Bosin was appointed Deputy Director of the SPC MR for scientific work, and Ph.D. in Engineering Mikhail Izrailevich Zelikman was appointed Associate Deputy of Yu.V. Varshavsky in the scientific and technical work.

In a short period of time, specialized scientific units were established, and prospects for individual scientific activity of employees were developed. Associate Professor Natalya Iosifovna Afanasyeva organized the work of the Academic Council, which was carried on for many years by Ph.D. in Medicine Elena Alexandrovna Pavlova.

THE ROLE OF SPC MR IN PROFESSIONAL ADVANCED TRAINING OF SPECIALISTS IN THE RADIOLOGY SERVICE

On the eve of the anniversary of the Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies of the Moscow City Health Department (SPCC DTT MCHD), a number of publications appeared in the press about the history of Moscow's radiology service, as well as very significant, striking changes that have occurred in the Center over the past 5 years.

The role of the SPC MR in organizing professional advanced training for radiology service specialists in Moscow is also noteworthy. Prior to the establishment of Diagnostic Center No. 3, the Training and Advisory Center CXRD, founded in 1977 on the basis of the city polyclinic No. 186 (chief physician Vladimir Dmitrievich Fedotov), was engaged in advanced radiology training in the Moscow Health Department, the educational department of which was headed by Igor Efimovich Kagan.

Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies of the Moscow City Health Department

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Meeting of the specialized certification commission

In 1996, in the established SPC MR, the tasks were defined to improve the organization of professional advanced training for specialists in the radiology service in Moscow. Professor Leonid Davidovich Lindenbraten, a well-known scientist and educator, led this field. Within the framework of the Central Certification Commission of the Moscow Health Department, a specialized certification commission was also formed to assign attestation categories to specialists in radiation diagnostics, led by a radiologist of the highest category, Maya Mikhailovna Lovkevich.

At the time of the renaming of the Diagnostic Center No. 3, Yury Viktorovich Varshavsky, Director of the SPC MR, and Professor Lyudmila Arsenyevna Nizovtsova, head of the organizational and methodological department, were employees of the Department of Radiation Diagnostics of the Russian Medical Academy of Postgraduate Education, which contributed to the joint activities of the Department and the Center, the introduction of all forms of postgraduate education of medical specialists in radiation diagnostics in the educational activities of the established SPC MR. Courtesy of the recognized professional and educator Viktor Vasilievich Kitaev, who headed the Information and Analytical Department of the SPC MR, advanced training was also organized for midlevel medical workers, X-ray technicians, and the involvement of the Center's chief nurse, senior X-ray technician Nelly Ivanovna Solovieva in this activity.

The work of well-known professionals such as Professor Nikolai Nikolaevich Blinov, Eduard Georgievich Chikirdin, Vladimir Vladimirovich Stavitsky, and Mikhail Izrailevich Zelikman in the SPC MR established advanced training of the medical and technical staff of the radiation diagnostics service in the field of radiological control and radiation safety. Almost immediately, a team of highly professional employees was organized, who were actively involved in the educational activities of the SPC MR of the Moscow Health Department in addition to their main functions. In fact, SPC MR was the country's first CXRD, combining scientific and full-fledged systematic work to improve the professional level of employees of the radiation diagnostics services in institutions subordinate to the Department of Health.

Joint work with the City Mammological Dispensary to improve the qualifications of radiologists in mammology was performed by Professor Larisa Markovna Burdina and Associate Professor Evsey Grigorievich Pinkhosevich, who was the organizer of the mammological service in Russia and the founder of the first City Mammological Dispensary in global practice (1990), which was transformed with his active participation into Women's Health Clinic in 2004.

Professor Viktor Yuryevich Bosin, in collaboration with the Pediatric Department of Radiation Diagnostics of the Russian Medical Academy of Postgraduate Education, actively participated in the advanced training of radiologists from children's institutions.

PROFESSIONAL EDUCATIONAL ACTIVITY OF RADIOLOGISTS

The professional educational activities of radiologists during the SPC MR period can be objectively divided into three stages, each of which corresponded to tasks assigned, created, and implemented in accordance with the plans of the administrative team.

The period 1996–2012 can be described as an active stage in the development of a new format of professional education, a network form of education. In Moscow, radiologists received primary professional education in the form of a 1-year internship or 2-year residency at the departments of universities and research institutes, and through the Department of Health, it was at the Second Moscow Medical Institute (N.I. Pirogov Russian National Research Medical University) (Head of the Department of Radiation Diagnostics Professor Andrey Leonidovich Yudin) and the N.V. Sklifosovsky Federal Research Institute of Emergency Medicine (Head of the Radiological Department was a well-known scientist and outstanding teacher Professor Era Arsenievna Beresneva).

Radiological Department of N.V. Sklifosovsky Federal Research Institute of Emergency Medicine (2004–2005)

Later, through the Healthcare Department, residents in the specialty "Radiology" were trained at the Research Institute of Emergency Pediatric Surgery and Traumatology (program leader Professor T.A. Akhadov) and the A.S. Loginov Moscow Clinical Research Center (program leader Professor A.B. Abduraimov). The SPC MR was tasked with supervising training in these institutions specifically designated by the Healthcare Department for groups of interns and residents.

Because of the current situation in the SPC MR, the work of the SPC staff representing the department of the Russian Medical Academy of Postgraduate Education (Yu.V. Varshavsky, L.A. Nizovtsova, M.I. Zelikman) and the Department of Radiation Diagnostics and Therapy of the Russian State Medical University (N.I. Afanaseva), there were real opportunities to conduct joint thematic cycles for residents and interns. Teachers at the N.V. Sklifosovsky Federal Research Institute of Emergency Medicine Professor Era Arsenievna Beresneva and her deputy Ph.D. in Medicine Irina Evgenievna Selina assisted in the delivery of these courses. Business and informal communication with Era Arsenievna, a wonderful teacher, a famous scientist devoted to traditional emergency X-ray diagnostics, and an amazing woman, left an indelible memory and bright warm impressions for everyone who was lucky enough to speak with her at least once.

The experience of teaching such general courses has demonstrated their effectiveness and the interest of students in taking them. Thus, in September 2000, in agreement with L.D. Lindenbraten, L.A. Nizovtsova organized the first course "Introduction to Specialty" for residents in their first year of study in all departments of radiation diagnostics of medical universities and research institutes located in Moscow. The scrupulousness of Ekaterina Sergeevna Kiseleva, an employee of the SPC MR, should be emphasized, who, in addition to her main duties, served as the dispatcher of the curriculum for these courses.

All departments were eager to hold classes at Kalitnikovskaya (audience of SPC MR). The authority in conducting these courses was created by the common interest of the curator and the teachers who fulfilled the curriculum, as well as the employees of all departments whose residents were trained on the course. Lectures by L.D. Lindenbraten in this cycle, particularly for his group seminars with residents, were held in high regard. The preparation of material for classes with residents by Leonid Davidovich, as well as his constant work to improve educational materials and manuals, left not only warm memories and pleasant impressions from communication with this amazing person but also an example of a teacher, scientist, and professional looking to the future. His constant improvement of his own publications, as well as his desire to create a new textbook for residents, sparked admiration. He stated unequivocally that a 2-year residency is insufficient time to prepare a qualified doctor with modern knowledge in this profession. His dream was to change and to reform professional education in radiology: "If I were a minister, I would restructure the specialty. It does not have to be just radiology."

We raised these concerns repeatedly during the preparation of the professional standard "Radiologist."

Residents after the lecture by E.A. Beresneva

In 2004, the course started to be held under the auspices of the Moscow Association of Medical Radiologists rather than the SPC MR. One of the reasons for this change was the creation in 2003 by Professor Alla Vladimirovna Zabrodina of a private educational institution Educational Center for Medical Radiology, which is located at the Scientific and Practical Center for Medical Radiology.

The educational activities of the SPC MR included not only the training of interns and residents but also advanced training courses for radiologists on a variety of topics. Nugzar Abesalomovich Shengelia, an employee of the SPC MR, actively conducted regular advanced training courses on radiation safety in X-ray examinations for both doctors and technical workers.

Seminar of Professor L.D. Lindenbraten with residents

The collaboration with V.V. Kitaev is remembered fondly for proposing a novel approach to advanced training of X-ray technicians. The work of the specialized certification subcommissions of the Central Certification Commission of the Moscow Department of Health was reorganized in 2000. Two certification subcommissions were approved in the SPC MR: for doctors (radiologists, ultrasound diagnostics and radiologists; executive secretary L.A. Nizovtsova) and paramedical workers (X-ray laboratory assistants, nurses of radiation diagnostics departments; executive secretary N.I. Solovieva). After 2012, both commissions were merged, and Yuri Yurievich Yurkin, Ph.D. in Medicine, was appointed secretary of the unified specialized certification commission. Since 2016, the structure of specialized certification commissions has changed several times. In addition, in 2000, a new approach to assessing the professional competence of specialists was developed for that time period, and test tasks and situational problems were formulated and then improved. The first situational problems for the qualification exam for X-ray technicians were created and published by V.V. Kitaev in 1998; and for the first time in 2001, tests for qualification exams for radiologists appeared not only in Moscow but throughout Russia. Everyone who knew Viktor Vasilyevich, a benevolent, sympathetic, widely erudite individual, remembered both the collaborative work and informal communication with great respect and warmth.

Since 2000, requirements for the digitalization of advanced training programs and control materials in educational and certification processes have been developed. Thus, this is a never-ending cycle of creation and improvement. Further,

we must pay tribute to Yu.V. Varshavsky, who enlisted not only the staff of the Department and the SPC MR but also the highly professional specialists in practical healthcare and related specialties, to this generally unappreciated creative endeavor, namely, the compilation of educational programs and test tasks. Probably for this reason, the materials created by the Department of Radiation Diagnostics of the Russian Medical Academy of Postgraduate Education have long served as a model for other educational institutions. The SPC MR created the first database of test tasks for certification examinations of medical specialists in radiation diagnostics, differentiated not only by specialty but also by declared certification category.

The period 2012–2015 should be attributed to the next stage in the development of professional educational activities at SPC MR. Professor Alexander Igorevich Gromov, who was the director of the SPC MR at the time, had to solve a number of key tasks assigned by the Moscow Department of Health, including licensing the educational and medical activities of the SPC MR; establishing a new administrative unit within the SPC structure, namely, the Training and Advisory Center; organizing telemedicine consultations for doctors of radiology departments of institutions subordinate to the Moscow Department of Health; and monitoring the staffing of radiology departments in the medical institutions of the Department of Health, etc.

Inna Vladimirovna Krinina, a highly qualified radiologist with extensive teaching experience at a medical university, took an active role in completing the tasks outlined above. She was the director of the SPC MR's Training and Advisory Center; she actively performed basic organizational work to obtain licenses for the educational activities of the SPC, as well as the preparation of postgraduate education programs for doctors and X-ray technicians. With the team she formed, the introduction of telemedicine consultations into clinical practice, as well as the audit of the work of departments of the radiology service, started. Due to the high level of interest shown by practicing physicians in advanced training courses held at the SP MR's Training and Advisory Department of the SPC MR, training in advanced education programs was introduced for radiation diagnostics specialists from institutions not subordinated to the Moscow Health Department, including on-site advanced training courses in other regions of the country.

Professor S.P. Morozov, Director of the Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies, President of the Moscow Regional Branch of the Russian Society of Radiologists and Radiologists

In 2015, Professor Sergey Pavlovich Morozov, who took over as director of the SPC MR, paid special attention to the activities of the Training and Advisory Department. Irina

Opening of a Training and Advisory Center on the M. Raskova street

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Head of the Training Center of the Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies Ph.D. in Medicine I.A. Trofimenko

Anatolyevna Trofimenko, a highly qualified radiologist and an energetic, proactive specialist with experience in pedagogical work, was appointed the head of this department and currently performs these functions successfully. Currently, the training center with an advisory department is one of the major subdivisions of the Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies of the Moscow Health Department (as the SPC MR was renamed in 2019), which actively competes with the departments of radiation diagnostics of major medical universities in Moscow and Russia.

Strategic creative collaboration of the director of the SPCC DTT MCHD S.P. Morozov and the head of the Training Center I.A. Trofimenko showed excellent results in organizing and implementing new forms of professional training for radiology specialists, specifically in preparing and conducting advanced training programs for radiology specialists of various levels, which were accredited by the Coordinating Council for the Development of Continuous Medical Education of the Ministry of Health of Russia; organizing courses of radiation diagnostics for doctors of clinical specialties; and promptly addressing the issues of distance learning for medical specialists in radiation diagnostics during the COVID-19 pandemic.

In its 5years of operation, about 900 full-time and part-time advanced training programs, master classes, webinars, and online meetups have been held at the Training Center. Thanks to the active work, more than 150,000 specialists, radiologists, ultrasound doctors, clinical specialists, X-ray technicians, and senior nurses, as well as heads of departments of radiation and ultrasound diagnostics, were able to acquire new competencies and improve their professional level within their existing qualifications.

The desire to comply with the provisions of the vocational training of the Bologna Agreement (1999), as well as the creation of conditions for obtaining European diplomas by Russian specialists, should be noted in the work of the Training Center. The SPCC DTT MCHD Training Center, which has earned a high reputation, is currently being involved by the Ministry of Health of Russia as an expert in resolving urgent problems of professional training and accreditation of radiology specialists.

Nowadays, the training center works with over 120 experts from Russia, neighboring countries, the USA, and Western Europe. They are all practitioners with thousands of studies under their belts who work in multidisciplinary teams.

Every year, an increasing number of specialists in related specialties attend all educational events hosted by

Director of the Scientific and Practical Clinical Center for Diagnostics and Telemedicine Technologies Professor S.P. Morozov at an open lesson at Training Center No. 1409

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the Training Center of the SPCC DTT MCHD and the Moscow Regional Branch of the Russian Society of Roentgenologists and Radiologists (MRB RSRR).

Combining the high level of professional educational activities of the training center with the multidisciplinary scientific activities of the SPCC DTT MCHD (which should be the subject of a separate report), the progressive development of the institution as a whole can be highlighted, and we wish the staff and administration of the SPCC continued progress, new achievements, and victories.

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Показатели магнитно-резонансной томографии как радиомные маркеры в дооперационном определении степени злокачественности внемозговых образований

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АННОТАЦИЯ

Обоснование. Внемозговые образования — одна из наиболее сложных групп для первичной дифференциальной диагностики. Определение радиомных маркеров и их стандартизация являются основными базовыми проблемами современного этапа развития медицины.

Цель — выявить радиомные маркеры для предоперационной оценки степени злокачественности внемозгового образования.

Материалы и методы. Ретроспективный анализ результатов исследований методом магнитно-резонансной томографии (1,5 Т) 156 пациентов с внемозговыми образованиями. Пациенты были разделены на 2 группы: (1) с наличием перифокальных изменений (*n*=106) и (2) внемозговым образованием без перифокальных изменений (*n*=50). В протокол сканирования были включены диффузионные и перфузионные последовательности. За зону интереса принимали (1) основной очаг и (2) зону перифокальных изменений. Выполнены измерения от основного очага и от зоны перифокальных изменений на картах измеряемого коэффициента диффузии, T2*-контрастной перфузии (DSC), проведен анализ серий динамического контрастирования (DCE).

Результаты. Максимальный размер основного очага (узла) поражения в 1-й группе составил 2,2 см (1,4; 4,3), во 2-й группе — 1,2 см (0,9; 3,5); ограничение диффузии от основного очага поражения выявлено у 42 (39,6%) человек 1-й группы и у 7 (14%) — 2-й. Максимальный размер перифокальных изменений в 1-й группе составил 2,85 см (1,5; 4,7). Ограничение диффузии от периферической зоны выявлено в 52 (49,1%) случаях. У пациентов 1-й группы с верифицированной менингиомой (*n*=66) путём многофакторного линейного регрессионного анализа выявлено, что максимальный размер основной зоны поражения увеличивал коэффициент объёмного кровотока (rCBF) от зоны перифокальных изменений в 3,3 раза (βcoef. 3,3, ДИ 1,27; 5,28; *p*=0,003), однако снижал показатель регионарного объёма крови (rCBV) в 4 раза (βcoef. 4, ДИ -7,46; -0,71; *p*=0,02).

Заключение. Перфузионные и диффузионные методы в сочетании с анатомическими последовательностями демонстрируют потенциал и могут выступать радиомическими маркерами при диагностике и лечении внемозговых образований. В дальнейшем наиболее перспективным выглядит выявление радиомических функциональных маркеров от зоны перифокальных изменений.

Ключевые слова: радиомика; внемозговое образование; менингиома; перифокальные изменения; степень злокачественности; диффузия; перфузия.

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Use of magnetic resonance imaging features as radiomic markers in pre-operative evaluation of extra-axial tumor grade

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ABSTRACT

BACKGROUND: Extra-axial tumors are one of the tumor groups with difficult primary differential diagnostics. Detection and standardization of radiomic markers are one of the main problems of our time.

AIM: To detect radiomic markers for preoperative assessment of extra-axial tumor grade.

MATERIALS AND METHODS: This study retrospective analyzed the magnetic resonance imaging (1.5 T) data of 156 patients with extra-axial tumors. Patients were divided into 2 groups: Group 1 (*n*=106) with perifocal changes and Group 2 (*n*=50) with extra-axial tumors without perifocal changes. Diffusion and perfusion sequences were included in the scanning protocol. The areas of interest include (1) the lesion and (2) the area of perifocal changes. Measurements were made from the lesion and the area of perifocal changes on ACD and DSC maps, DCE was analyzed.

RESULTS: The maximum lesion size in Group 1 was 2.2 cm (1.4; 4.3), whereas in 1.2 cm in Group 2 (0.9; 3.5). In Group 1, the diffusion restriction from the lesion was detected in 42 patients (39.6%), whereas 7 (14%) in Group 2. The maximum size of perifocal changes in Group 1 was 2.85 cm (1.5; 4.7). Diffusion restriction was detected in 52 (49.1%) cases. In Group 1, patients with verified meningioma multivariable linear regression analysis showed 3.3-times increase of rCBF of the maximum size of the lesion from the area of perifocal changes (βcoef. 3.3, CI: 1.27; 5.28), *p*=0.003; however, it demonstrated a 4-time decrease of rCBF (βcoef. 4 CI: -7.46; -0.71), *p*=0.02.

CONCLUSIONS: Perfusion and diffusion methods combined with anatomical sequences show potential use as radiomic markers for diagnostic assessment and treatment of extra-axial tumors. Further detection of radiomic functional markers from the area of perifocal changes has potential.

Keywords: extra-axial tumors; meningioma; perifocal changes; malignancy grade; diffusion; perfusion.

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磁共振成像指标作为术前确定脑外组织恶性程度的放射标记物

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简评

论证。脑外结构是最难进行初级鉴别诊断的组之一。 放射组标志物的测定及其标准化是现代医学发展阶段的主要基础问题。

目标是确定用于术前评估脑外肿块恶性程度的放射组标记。

材料与方法回顾性分析使用磁共振成像 (1.5 T) 对 156 名脑外形成患者的研究结果。将患者分为 2 组：(1) 存在病灶周围改变（*n*=106）和 (2) 无病灶周围改变的脑外肿块（*n*=50）。 扩散和灌注序列包括在扫描协议中。 感兴趣的区域被定义为 (1) 主要焦点和 (2) 焦点周围变化的区域。从主焦点和测量扩散系数图上的焦周变化区域进行测量，T2*-对比灌注 (DSC)，进行动态对比增强 (DCE) 系列分析。

结果。第 1 组主要病灶（节点）的最大尺寸为 2.2 厘米 (1.4；4.3)，第 2 组为 1.2 厘米 (0.9；3.5)； 第 1 组 42 人 (39.6%) 和第 2 组 7 人 (14%) 检测到主要病灶扩散受限。 第 1 组的最大焦周变化为 2.85 厘米 (1.5；4.7)。 在 52 例 (49.1%) 病例中检测到来自外周区的扩散受限。 在第 1 组确诊脑膜瘤患者（*n*=66）中，多元线性回归分析显示，主要病变区的最大尺寸使病灶周围变化区的体积血流系数（rCBF）增加了 3.3 倍(β coef. 3.3, CI 1.27; 5.28; *p*=0.003)，但将局部血容量 (rCBV) 降低了 4 倍 (β coef. 4, CI -7.46; -0.71; *p*=0.02)。

结论。灌注和扩散方法与解剖序列相结合显示出潜力，可以作为诊断和治疗脑外病变的放射组学标志物。 未来，最有希望的是从焦周变化区域识别放射功能标志物。

关键词：放射组学； 脑外教育； 脑膜瘤； 焦周变化； 恶性程度； 扩散；灌注。

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BACKGROUND

Medical images comprise huge amounts of information; therefore, radiomics in medicine has been actively developing in the last decade [1]. It looks promising to study texture analysis for differential diagnostics and functional analysis and to determine the disease prognosis [2]. Radiomics in oncology is the most demanded [3]. However, at the start of each work using a new diagnostic method, researchers face the problem of recognizing radiomic markers.

Extra-axial intracranial tumors are one of the least studied issues in neuroradiology, and meningiomas are the most common among them [4]. Different variants of meningiomas are described in detail in the literature [5]. Moreover, in ~15% of cases, atypical meningiomas of G2 or higher are detected [6]. Modern methods of pathomorphology help determine the grade by one criterion, namely, the presence of four mitoses in the field of view, which indicates the development of atypical meningioma [7]. However, the identification of radiome markers and further work in this field may enable, within the framework of preoperative diagnostics, drawing a conclusion about the tumor grade, which will affect not only the approach of surgical intervention but also the improvement of treatment results.

In the presence of focal pathology, the radiologist should determine lesion genesis, assess the localization (intracerebral or extra-axial), and exert every effort to suggest the grade of tumor genesis. At the current stage of development in medicine, no exact tomographic criteria have been established to distinguish meningioma from similar pathologies, such as hemangiopericytoma [7] or solitary fibrous tumor of the dura mater. Thus, using the term "meningioma" in primary diagnostics of histologically unverified tumor is reasonable. In such cases, in clinical practice, when performing magnetic resonance imaging (MRI), it may be probably worth using the terms "extra-axial tumor" or "neoplasm of the meninges" according to the International Classification of Diseases. Possibly, the most important task in primary diagnostics of a tumor is not the determination of the histological type but the suggestion of the neoplasm grade.

This study aimed to identify radiomic markers for the preoperative assessment of the severity of malignancy of an extra-axial lesion.

MATERIALS AND METHODS

Study design

An observational single-center retrospective uncontrolled study was conducted.

Inclusion criteria

The *inclusion criteria* were as follows: presence of an intracranial lesion with changes in the cortico-subcortical regions, results of a postoperative pathomorphological study, and findings from diffusion-weighted imaging (DWI), dynamic contrast enhancement (DCE), and T2*-contrast perfusion (DSC) in the scan protocol.

The *exclusion criteria* were as follows: absence of pathomorphological verification and absence of DCE and/or DSC in the scan protocol.

Research conditions

A retrospective analysis of the MRI data of the cranial zone was performed. MRI examinations were performed from 2017 to 2021.

Description of medical intervention

The MRI protocols of the cranial region were analyzed. All studies were performed on a Philips Achieva 1.5 T apparatus (Netherlands) using a multichannel head coil. In the MRI of the brain as part of the scanning protocol, the sequences of T2-weighted imaging (WI)), T1-WI, fluid-attenuated inversion recovery (FLAIR), DWI (maximum b-factor 1000 s/mm^2), followed by automatic mapping of the measured apparent diffusion coefficient (ADC), were analyzed.

Contrasting technique. The dose of the contrast agent was divided into two injections. DCE was performed at the first injection. Immediately after the DCE data collection, the second injection was performed, and T2* dynamic susceptibility contrast (DSC) was collected. After DSC, without additional injection of a contrast agent, a T1-weighted 3D sequence was performed, followed by a T1 spin echo in the axial plane. When assessing perfusion, relative values were used (the ratio to a symmetrically located unchanged area in the opposite hemisphere).

Image segmentation and identification of radiomic markers. According to the data obtained, the main focus and zone of perifocal changes were segmented semi-automatically by an experienced radiologist (more than 15 years of experience in onco- and neuroradiology) and then measured on the ADC and DSC maps, including DCE analysis.

Main study outcome

The primary endpoint was an extra-axial lesion identified on MRI.

Additional study outcomes

The secondary endpoint was the qualitative assessment of the diffusion pattern according to DWI, results of the quantitative assessment of ADC values, assessment of the dynamic curve from the zone of perifocal infiltration, and assessment of perfusion maps.

Subgroup analysis

The study participants were distributed into two groups: group 1 included patients with perifocal changes and group 2 (comparison group) included patients with extra-axial lesion without perifocal changes.

Outcome registration methods

After MRI, all patients underwent surgical treatment and pathomorphological verification of the lesion.

Ethical considerations

The paper analyzes the database of the institution. During hospitalization, all patients provided informed consent to the processing of personal data, including medical records, in the center to implement the educational process, scientific research, and publication in scientific literature, subject to medical secrecy.

Statistical analysis

Sample size calculation principles. When planning and conducting the study, the sample size to achieve the required statistical power of the results was not calculated. In this regard, the sample of participants obtained during the study cannot be considered sufficiently representative; this prevents extrapolating the results and their interpretation to the general population of similar patients outside the study.

Methods of statistical data analysis. Stata 13 program (StataCorp LP, CollegeStation, TX, USA) was used for data analysis. The normality of the distribution of characteristics was assessed using the Shapiro–Wilk test. The equality of variances of the distribution of characteristics was calculated using the Levene test. For descriptive statistics of normally distributed characteristics with equality of variances, the mean values and standard deviations were calculated. Qualitative variables are presented as numbers (%), quantitative variables as median (25th and 75th percentile), unless otherwise indicated (Q1; Q3). A regression analysis was performed to identify predictor variables for a binary response variable using simple and multiple logistic regression scores. Proportional hazards regression was used to evaluate the relationship between one or more continuous or categorical variables before an adverse event. The significance level for all methods used was set as $p < 0.05$.

RESULTS

Study participants

According to the inclusion criteria, 156 patients were enrolled in the study. The mean patient age was 50.63 ± 6.41 years.

All patients underwent surgical treatment after MRI, and pathomorphological verification of the lesion was performed. The patients were distributed into two groups: group 1 had perifocal changes (n = 106), and group 2 had extra-axial lesion without perifocal changes (n = 50). Pathological characteristics are presented in Table 1.

Table 1. Pathomorphological characteristics of the lesions

Pathological characteristics	Number of patients, *n*
Encephalopyosis	2
Metastatic lesion (breast cancer or lung cancer)	30
Typical meningiomas G1	100
Atypical meningiomas G2–3	16
Hemangioblastoma G1	1
Neurinoma G1	7

Main results of the study

The maximum size of the main lesion (node) was 2.2 cm (1.4–4.3) in group 1 and 1.2 cm (0.9–3.5) in group 2. Restriction of diffusion from the main lesion was detected in 42 (39.6%) patients in group 1 and in 7 (14%) patients in group 2.

The maximum size of perifocal changes in group 1 was 2.85 cm (1.5–4.7). Diffusion restriction from the peripheral zone was detected in 52 (49.1%) cases.

In group 1, the ADC value was determined from both the detected focus and the zone of perifocal changes in various pathologies (Table 2). The ADC value from the brain tissue adjacent to the node in group 2 was $0.71 \pm 0.07 \times 10^{-3}$ mm^2/s.

In group 1, a multivariate linear regression analysis revealed that in patients with verified meningioma (n = 66), the maximum size of the main lesion zone increased the coefficient of volumetric regional cerebral blood flow (rCBF) from the zone of perifocal changes by 3.3 times (βcoef. 3.3; confidence interval 1.27–5.28), p = 0.003 (Fig. 1); however, it reduced the cerebral blood volume (rCBV) by four times (βcoef. 4; CI –7.46 to –0.71), p = 0.02 (Fig. 2).

The analysis of DCE values in group 2 did not reveal a correlation between the tumor size and DCE from the area of perifocal changes, in contrast to perfusion maps (Fig. 3).

Additional research results

To introduce the work results into the clinical practice in case of newly diagnosed extra-axial lesion, an algorithm for using MRI techniques was proposed (Fig. 4).

Adverse events

No adverse events occurred.

DISCUSSION

Radiomic markers help obtain new results from long-used medical images. Moreover, radiomics is a recently emerging and rapidly developing area. Currently, all works are focused on the segmentation of the main tumor focus. However, in the world literature, no studies have investigated tissue characteristics around the lesion.

Gliomas are the most studied area in neuroradiology. A study discussed the results of the assessment of perifocal changes in gliomas [8], where tumor infiltration is formed

Table 2. Perfusion and diffusion values of perifocal changes for various brain pathologies in group 1

Brain pathology	ADC (×10^{-3} mm^2/s)		DSC relative to the contralateral hemisphere		DCE	
	From the node	From perifocal changes	From the node	From perifocal changes	From the node	From perifocal changes
Typical meningioma G1	1.52 ± 0.95	1.78 ± 0.73	Unaltered, may be slightly increased	Unaltered or decreased	Various	Various
Atypical meningioma G2–G3	0.72 ± 0.05	1.13 ± 0.86	Increase in rCBF, decrease in rCBV	Increase in rCBF, decrease in rCBV	Various	Various
Metastasis	1.03 ± 0.15	1.55 ± 0.23	Increased	Unaltered or decreased	Various	Unaltered, no early accumulation
Neurinoma	1.2 ± 0.04	1.56 ± 0.06	Unaltered or decreased	Unaltered or decreased	Unaltered, no early accumulation	Unaltered, no early accumulation
Abscess	0.63 ± 0.04	1.26 ± 0.06	Decreased	Unaltered or decreased	No early accumulation	Unaltered, no early accumulation

Note. ADC, apparent diffusion coefficient; DSC, T2* perfusion; DCE, dynamic contrast enhancement.

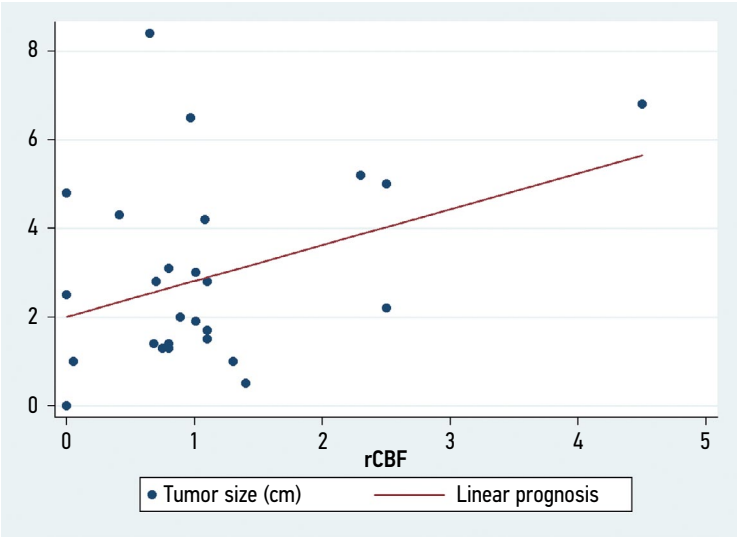

Fig. 1. Linear regression analysis: relation between tumor size and CBF rate

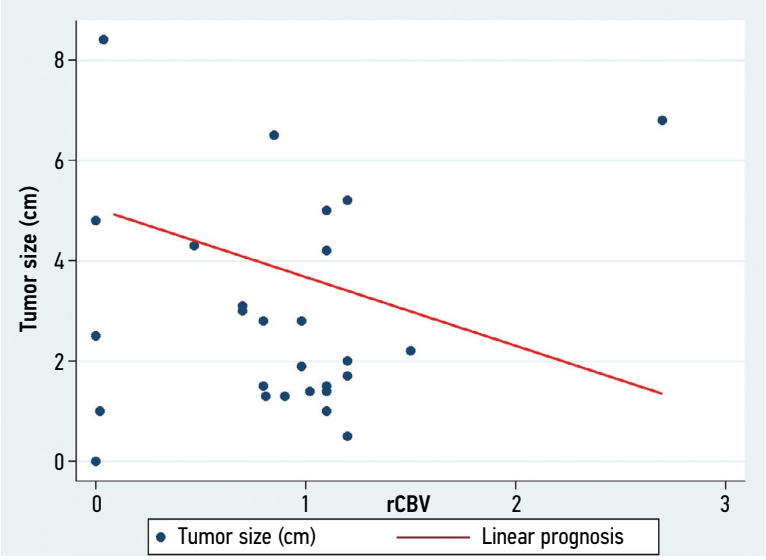

Fig. 2. Linear regression analysis: relation between tumor size and CBV rate

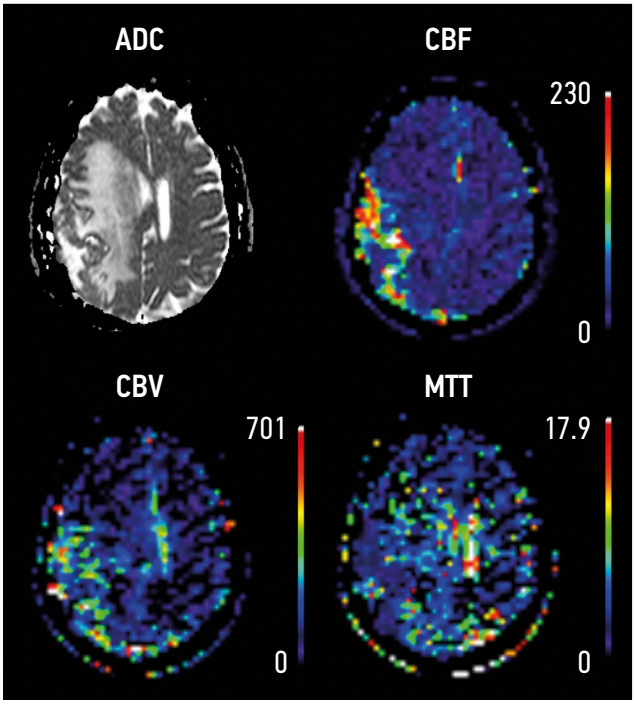

Fig. 3. Atypical meningioma: ADC — apparent diffusion coefficient; CBF — cerebral blood flow, CBV — cerebral blood volume, MTT — mean transit time.

around the glial tumor. Moreover, perifocal changes in extra-axial tumors have been under-investigated. We managed to find a very limited number of studies that have investigated perifocal changes in extra-axial lesions [9].

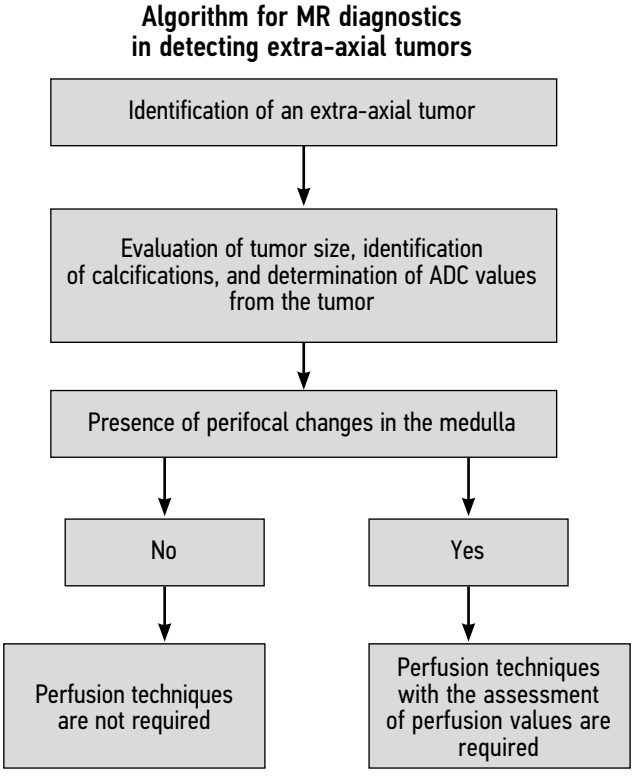

Fig. 4. Algorithm for MR-diagnostics of primarily detected extra-axial tumors.

In addition, the indicators used in radiomics are not standardized, as are the MRI sequences used, which makes both the process and the results difficult to replicate and scale. Very few studies have investigated effective radiomic markers.

Summary of the main results

In this study, indicators that are the most promising for use in the further development of radiomics were investigated. These indicators include DWI, ADC values, and perfusion parameters. A multivariate linear regression analysis of the correlation of indicators was performed (CI –7.46 to –0.71), $p = 0.02$ (Fig. 2).

Analysis of DCE values in group 2 did not reveal a correlation between tumor size and DCE values.

Discussion of the main results

In clinical practice, to detect an extra-axial neoplasm through MRI, not only the structure of the neoplasm should be assessed, but precise perifocal changes must be identified or ruled out since in our studies of patients without perifocal changes, not a single malignant meningioma was detected. Thus, the result of this study demonstrates that the absence of perifocal changes virtually excludes the malignancy of the lesion detected.

In clinical practice, to rule out perifocal changes in the presence of an extra-axial lesion, it is sufficient to use FLAIR as a sequence in which infiltrative or edematous changes become the most demonstrative. The absence of perifocal changes does not guarantee the absence of atypia in this tumor; just as in the presence of perifocal changes, an atypical morphological presentation will not always be obtained. However, because of the complexity of differential diagnostics and the absence of direct criteria indicating atypia, there is a pronounced need to use all criteria, including indirect ones. A set of indirect criteria in most cases will determine the decision of the radiologist.

To detect perifocal changes on MRI, it is important to assess their genesis (ischemia, vasogenic or cytotoxic edema, and infiltration). To date, DWI is used in every brain scan protocol. Ischemic brain changes in DWI have been evaluated in detail in contrast to perifocal changes in extra-axial lesions. In differential diagnostics of the changes, it is important to analyze not only the presence of diffusion restriction but also the ADC maps. This is required primarily to eliminate the effect of T2 transillumination and avoid false-positive results and, secondly, to determine the ADC value.

The results of this study revealed that different ADC values were obtained from both the node and perifocal changes. The ADC value from the adjacent medulla in the presence of an extra-axial tumor, but in the absence of perifocal changes, was $0.71 \pm 0.07 \times 10^{-3}$ mm^2/s. The significant difference in the ADC values from the medulla and from perifocal changes in meningiomas is prognostically interesting in terms of its consideration for preoperative assumptions about the grade.

In our opinion, an important limiting factor affecting the ACD value is the presence of calcifications in the tumor, since they will distort the value or completely prevent its adequate calculation. However, the presence of calcifications in a meningioma is a clear sign of the absence of growth in it; as a result, the development of cell atypia becomes even less probable [10].

We also performed MR perfusion. In the present study, to analyze the identified changes, two types of MR perfusion using a contrast agent were employed, namely, DSC and DCE. Studies have described the use of perfusion techniques in various pathologies [11, 12]. In brain examination, DCE can be included in the scanning protocol to assess the vascular wall permeability [13, 14].

According to the literature, the use of perfusion methods appears appropriate in the differential diagnostics of typical and atypical meningiomas. However, according to our results and those of several authors, evaluating perifocal changes is important to make an adequate decision about the expected grade [15].

A study reported that the greatest increase in perfusion values relative to the opposite hemisphere will be registered in cases of angiomatous meningioma [15] and atypical meningioma, which was also demonstrated in our work.

With further case follow-up and absence of histological verification, in our opinion, the proposed algorithm can be applied with a mandatory assessment of the tumor growth and the emergence/growth of perifocal changes.

In case of a history of histological verification, the use of perfusion techniques is not required in a typical meningioma (G = 1). In this case, to assess continued growth or recurrence, contrast enhancement without perfusion protocols is sufficient; however, the need to assess atrophic changes in the medulla in the site of surgical intervention should be considered. When meningioma atypia is confirmed (G = 2–4), perfusion techniques are necessary to assess the dynamics of changes. In the dynamic study of atypical meningiomas, it is important to consider the type of surgical treatment performed, such as surgical removal, radiation therapy, and embolization of tumor afferents, etc. This approach is similar to the glioma monitoring protocol.

With an increase in the tumor size and presence of perifocal changes, the need to assess the perfusion maps in correlation with the ACD value as a predictor of the severity of malignancy is clear.

Study limitations

Our results on DCE indicate that the issue of using DCE to assess the severity of malignancy of an extra-axial lesion in clinical practice remains open and requires further investigation.

CONCLUSION

Perfusion and diffusion methods combined with anatomical sequences demonstrate potential and can be used as radiomic markers in the diagnostics and treatment of extra-axial lesions. In the future, the identification of radiomic functional markers from the zone of perifocal changes is the most promising.

ADDITIONAL INFORMATION

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Радиомика магнитно-резонансной томографии при раке предстательной железы: что известно в настоящее время?

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АННОТАЦИЯ

Подходы к диагностике и лечению рака предстательной железы опираются на комбинацию данных магнитно-резонансной томографии и гистологических данных.

Цель данного обзора — введение читателя в основы современного диагностического подхода к раку предстательной железы при помощи магнитно-резонансной томографии с фокусом на текстурный анализ цифровых медицинских изображений.

Текстурный анализ позволяет оценить взаимосвязи между пикселями изображения с помощью математических методов, что даёт дополнительную информацию, в первую очередь о внутриопухолевой гетерогенности. Текстурный анализ признаков первого порядка может иметь бóльшую клиническую воспроизводимость, чем текстурные характеристики более высокого порядка. Текстурные особенности, извлечённые из карт коэффициента диффузии, показали наибольшую клиническую значимость.

Будущие исследования должны быть направлены на интеграцию методов машинного обучения для облегчения использования текстурного анализа в клинической практике. Требуется развитие автоматизированных методов сегментации для уменьшения вероятности включения нормальных тканей в области интереса и ускорения получения результатов анализа. Для проверки диагностического потенциала текстурных признаков требуются крупные проспективные исследования.

Ключевые слова: рак предстательной железы; магнитно-резонансная томография; МРТ; радиомика.

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Magnetic resonance imaging radiomics in prostate cancer radiology: what is currently known?

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ABSTRACT

Diagnostic and treatment approaches in prostate cancer rely on a combination of magnetic resonance imaging and histological data.

This study aimed to introduce the basics of the current diagnostic approach in prostate cancer with a focus on texture analysis.

Texture analysis evaluates the relationships between image pixels using mathematical methods, which provide additional information. First-order texture analysis of features can have greater clinical reproducibility than higher-order texture features. Textural features that are extracted from diffusion coefficient maps have shown the greatest clinical relevance. Future research should focus on integrating machine learning methods to facilitate the use of texture analysis in clinical practice.

The development of automated segmentation methods is required to reduce the likelihood of including normal tissue in the area of interest. Texture analysis allows the noninvasive separation of patients into groups in terms of possible treatment options. Currently, few clinical studies reported on the differential diagnosis of clinically significant prostate cancer, including the Gleason and International Society of Urological Pathology grading. Large prospective studies are required to verify the diagnostic potential of textural features.

Keywords: prostate cancer; magnetic resonance imaging; MRI; radiomics.

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前列腺癌磁共振成像的放射组学：目前已知的是什么？

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简评

前列腺癌的诊断和治疗方法依赖于磁共振成像和组织学数据的结合。

这篇综述的目的是向读者介绍利用磁共振成像对前列腺癌进行现代诊断的基本方法，重点是数字医学图像的纹理分析。

纹理分析使使用数学方法评估图像像素之间的关系成为可能，这提供了额外的信息，主要是关于肿瘤内异质性的信息。一阶特征的纹理分析可能比高阶纹理特征具有更大的临床再现性。从扩散系数图中提取的纹理特征具有最大的临床意义。

未来的研究应侧重于整合机器学习技术，以促进纹理分析在临床实践中的应用。需要开发自动分割方法，以降低将正常组织纳入感兴趣区域的可能性，并加快分析结果的传递。为了测试纹理特征的诊断潜力，需要进行大规模的前瞻性研究。

关键词：前列腺癌；磁共振成像；磁共振成像；无线电麦克风。

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INTRODUCTION

For early diagnosis of prostate cancer, a prostate-specific antigen test is used. With an increase in its level, digital rectal examination and magnetic resonance imaging (MRI) are recommended. The prostate-specific antigen test is not recommended as a population-screening test because it is considered insufficiently specific or sensitive to detect clinically significant prostate cancer [1]. Transrectal ultrasound-guided biopsy is the most common method of morphological verification; however, this method has several limitations, including the high risk of infection and hemorrhage and difficulties in accessing the anterior gland, especially with an increase in its volume. Prostate cancer is considered clinically significant if at least one lesion with a score of 3 + 4 on the Gleason scale is detected; a small Gleason 3 + 3 lesion is considered clinically insignificant [2].

Multiparametric MRI before biopsy increases the probability of detecting clinically significant prostate cancer from 26% to 38% compared with transrectal ultrasound-guided biopsy [2].

The PROMIS study has shown that in one-fourth of men, MRI helped avoid unnecessary biopsies [3]. The use of the Prostate Imaging–Reporting and Data System (PI-RADS), created as part of an international collaboration between the American College of Radiology and the European Society of Urological Radiology (ESUR) [4], has become widespread.

With clinical practice transferring to pre-biopsy MRI of the prostate gland as the standard of medical care, there is growing interest in the possibility of using radiomics to improve the diagnostic accuracy of prostate MRI.

Radiomics enables the extraction of quantitative indicators from a diagnostic image, which can be analyzed to obtain prognostic information [5]. These quantitative indicators can provide important insight into the phenotype of prostate cancer and potentially help make a diagnosis and improve the assessment of response to treatment [6].

DIAGNOSTICS OF PROSTATE CANCER

Pathomorphology

Most validation studies on texture analysis in prostate cancer have used the traditional Gleason system as a reference. This system is based on five main assessments of the histological structure of prostate tissue [7]. In 2014, the International Society of Urological Pathology (ISUP) simplified the Gleason scale to more accurate prognostic groups (from ISUP 1 to ISUP 5). The most important amendment was the division of the Gleason sum of 7 into two prognostic groups (i.e., 3 + 4 and 4 + 3); in future validation studies, comparing the results of texture analysis with pathological changes according to ISUP is recommended.

Multiparametric MRI

MRI of the prostatic gland is the most widely used method for clarifying the diagnosis of prostate cancer. The main techniques include T2-weighted and diffusion-weighted imaging, dynamic contrast enhancement, and MR spectroscopy.

Using T2-weighted images, the zonal structure of the prostate gland can be differentiated. If the peripheral zone (PZ) contains a tumor node, it will look similar to an area with low signal intensity [8]. The main problem is that low signal intensity can also be registered in benign abnormalities, such as prostatitis, fibrosis, and hemorrhage after biopsy [1]. The advantage of T2-weighted images is the ease of data collection and lower susceptibility to artifacts than functional sequences [9].

Tumor vascularization is assessed using T1-weighted images using an intravenous gadolinium-based contrast agent [1]. The walls of the vessels in the tumor are more permeable, due to which extravasation of the contrast agent is noted in tumors [8]. With dynamic contrast enhancement, quantitative indicators, such as volumetric transfer coefficient (K_{trans}) and extracellular volume (Ve), can be extracted. K_{trans} describes microvascular permeability and blood flow, whereas Ve describes the extravasation volume [1]. As a rule, tumors show early contrast enhancement, followed by a washout effect. As in the case of T2-weighted images, contrast enhancement can also correspond to benign processes, such as prostatitis and benign hyperplasia nodules. Simultaneously, dynamic contrast enhancement is extremely important in the search for residual or recurrent tumors after prostatectomy [1].

Diffusion-weighted images reflect the Brownian motion of water molecules in tissues [10]. The data obtained help estimate the level of water diffusion in tissues. For quantification, a measured diffusion coefficient (MDC) is used [1]. Several studies have presented a significant inverse relationship between the MDC values and the Gleason scale in tumors of the PZ of the prostate gland [11]. Diffusion-weighted images are considered the most important for the differential diagnosis of tumors of the PZ of the prostate gland [1]. Thus, when performing prostate MRI, T2- and diffusion-weighted images are the most informative for the detection and differential diagnosis of tumor foci in the PZ.

The PROMIS study has shown that MRI of the prostate gland is more sensitive than biopsy in detecting clinically significant tumors but less specific [3]. One of the main limitations of prostate MRI is the differences in imaging quality between centers. Although the PI-RADSv2 data assessment system has helped standardize the interpretation of prostate MRI, it has been less successful in ensuring the accuracy and reproducibility of the data obtained [1]. Texture analysis can be used to solve this problem.

Texture analysis

Radiomics is a developing field that involves the conversion of digital medical images into retrievable image quantitative indicators based on signal intensity, shape, volume, and textural characteristics of lesions, for assessing

Table 1. The definitions of first-order textural characteristics

Textural characteristics	Definition
Mean	The average value of the signal intensity of the pixels in the region of interest
Standard deviation	Deviation of the signal intensity of the pixels in the region of interest compared with the average values
Skewness	Skewness of the signal intensity distribution in pixels in the region of interest (on the histogram)
Kurtosis	The height and sharpness of the central peak of the histogram compared with the normal distribution curve
Entropy	The number of different variants of pixel signal intensities in the region of interest
Energy	The degree of image uniformity
Average positive pixels	The average number of positive pixels (which are brighter than the average pixel)

intratumoral heterogeneity [12]. Texture analysis enables the evaluation of the patterns of signal intensity, which can be used to quantify suspicious areas. In oncological imaging, there is a growing interest in texture analysis and radiomics due to the possibility of extracting additional quantitative data from standard medical images, which can improve the accuracy of diagnostics and clinical decisions [13]. Texture analysis uses mathematical methods to estimate the intensity of gray color and the location of pixels in an image [14]. First-order texture analysis, otherwise known as histogram analysis, extracts the intensity values of the pixels in the area of interest, which are then displayed graphically [5]. Simplified texture analysis involves the initial adjustment of an image by applying fine, medium, and coarse filters to the image, allowing the extraction and quantification of image characteristics invisible to the naked eye in terms of unevenness and brightness. Moreover, medium and coarse filters enhance vascular structures and other discriminatory signs in the image*. Based on the histogram, metrics are calculated, including uniformity, dispersion, symmetry, and randomness of pixel intensity values within the region of interest [15]. The most common characteristics of the histogram, which are given in published sources, are the mean, standard deviation, skewness, kurtosis, entropy, and energy [5] (Table 1).

A more complicated radiomic analysis of image aspects investigates the relationships between pixels within a region of interest. More information on the intensity variability of the pixel signal in smoother, more uniform areas that have less texture variability or more heterogeneous areas that have greater texture variability can be obtained.

Second-order statistics, also called Haralick features, compare the relationship between two pixels, whereas higher-order texture analysis compares the relationship between more than two pixels. Second-order functions are based on gray-level co-occurrence matrix (GLCM). Colloquially speaking, they describe the frequency of occurrence of a gray tone in an image in a spatial relationship with another gray tone [16]. Higher-order functions are based on neighborhood gray-tone difference matrix (NGTDM) or gray-level run length matrix [17]. GLCM indicates the spatial relationship between three-dimensional pixels (voxels) in a certain direction and the properties of uniformity, randomness, and linear dependence of the image. NGTDM is based on differences between neighboring voxels [18]. The signs most commonly mentioned in published studies include energy, homogeneity, contrast, GLCM entropy, and correlation [15].

Segmentation

Figure 1 illustrates a simplified workflow demonstrating the path to implementing texture analysis in clinical practice. This entails several key steps [5], which are detailed below.

Accurate segmentation of the tumor is a critical initial step in the workflow. The work of E. Scalco and G. Rizzo [15] has shown that all characteristics of the histogram and matrix are affected by the segmentation method. The inclusion of healthy tissues in the segmentation region can affect the results of texture analysis.

Prostate cancer, similar to any other tumors, most often has poorly defined boundaries, which can hinder manual segmentation. Most published studies evaluating textural analysis of the prostatic gland have used manual segmentation based on a single axial image. A more advanced method is the segmentation of the entire tumor volume [19].

An important methodological approach is layer-by-layer comparison of pathomorphological data and radiation diagnostic images, which is difficult to implement in segmentation based on a single axial image. The quality of the MR study, namely, the planning of sections with the same geometry, is also important for correct textural analysis. However, there is little evidence yet on the value

* TexRAD. Quantitiative textural analysis. Available from: https://fbkmed.com/texrad-landing-2.

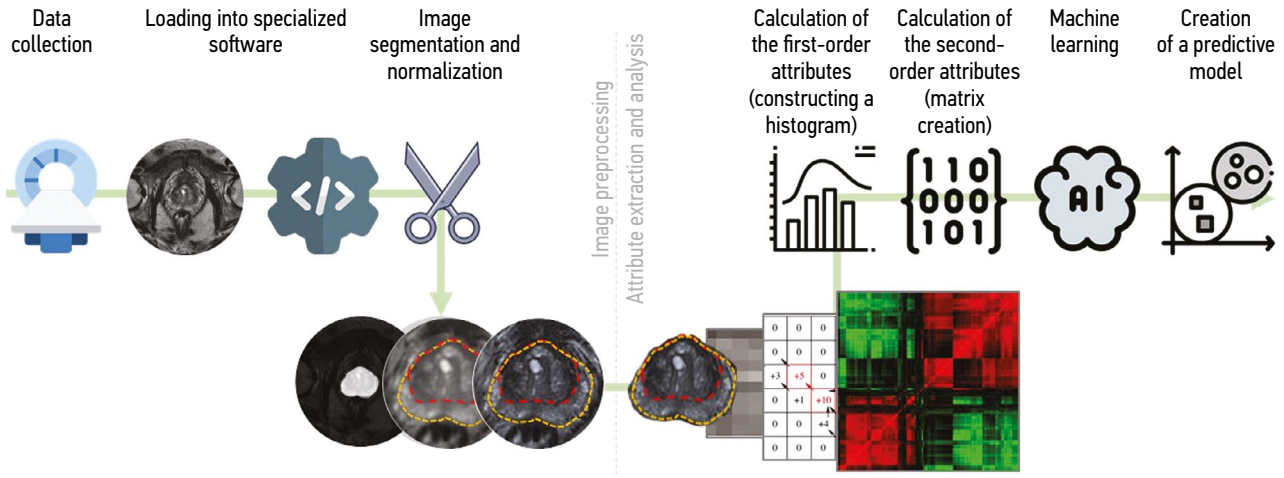

Fig. 1. Radiomics workflow model based on T2-weighted images in prostate cancer

of automated segmentation techniques for whole tumor evaluation in prostate cancer, and this should be evaluated in future prospective studies.

Software packages

Various open-source and commercial software packages are available for texture analysis of visualization data. In their recent review, R.T. Larue et al. [18] have provided a detailed overview of various software packages, including information on the types of imaging techniques supported, image preprocessing steps, and feature extraction. The LIFEx open-source software package is widely known, which allows for multimodal radiometric analysis of medical images.

The two main commercial software packages, TexRAD and RADIOMICS, use the Laplacian of Gaussian filter as part of image and function preprocessing, which can significantly reduce the image noise level, making detecting areas of signal intensity variation possible [20].

Preprocessing is important, as it allows correcting magnetic field inhomogeneities and normalizing the signal intensity both in a particular study and in a dataset [18]. Unfortunately, data to support the benefits of one software package over others are currently inadequate.

Texture analysis in the diagnosis of peripheral cancer

The largest patient cohort studied to date (n = 147) has assessed the potential value of texture analysis for the differential diagnosis of clinically significant peripheral prostate cancer and benign lesions in two studies. D. Fehr et al. [21] have used the same cohort of patients as A. Wibmer et al. [16] but increased the proportion of assessed segments of the transition zone and the number of identified textural characteristics. GLCM entropy and correlation extracted from T2-weighted images showed significant differences between benign and malignant tumors in both studies. All textural characteristics extracted from diffusion-weighted images showed a high significance level, leading to the recommendation of using first- and second-order statistics in diagnosing clinically significant peripheral prostate cancer [21].

Texture analysis in the diagnosis of cancer of the transitional zone

Additionally, numerous studies have reported conflicting results regarding texture analysis of transient zone (TZ) cancer. Thus, A. Wibmer et al. [16] did not reveal significant differences in the textural characteristics of diffusion-weighted images between tumors in the PZ and those in the transition zone. An example of entropy estimation is presented in Figure 2.

In T2-weighted images, only correlation and contrast were significant characteristics in both TZ and PZ texture analysis [16]. In their work involving 26 patients, H.S. Sidhu et al. [22] have revealed that kurtosis and entropy extracted from diffusion- and T1-weighted images were significant tumor predictors. The values of kurtosis decreased after resection of the tumor focus from the cut.

Textural analysis in the characterization of clinically significant prostate cancer

Few studies have explored the potential value of textural analysis in predicting the grade of prostate cancer. Few researchers have reported that textural characteristics correlate with the Gleason scale [23]. In their works, A. Wibmer et al. [16] have indicated that characteristics extracted from diffusion-weighted images can reliably distinguish lesions with a Gleason score of 6 from those with a Gleason score of 7, but not 3 + 4 lesions from 4 + 3 lesions. These preliminary results could conclude that textural analysis can detect a tumor and differentiate it from a benign process; however, the assessment of the focus pathomorphology can be difficult.

Recently, the systematic review by P.S. Sierra et al. [24] involving numerous studies has examined the usefulness of

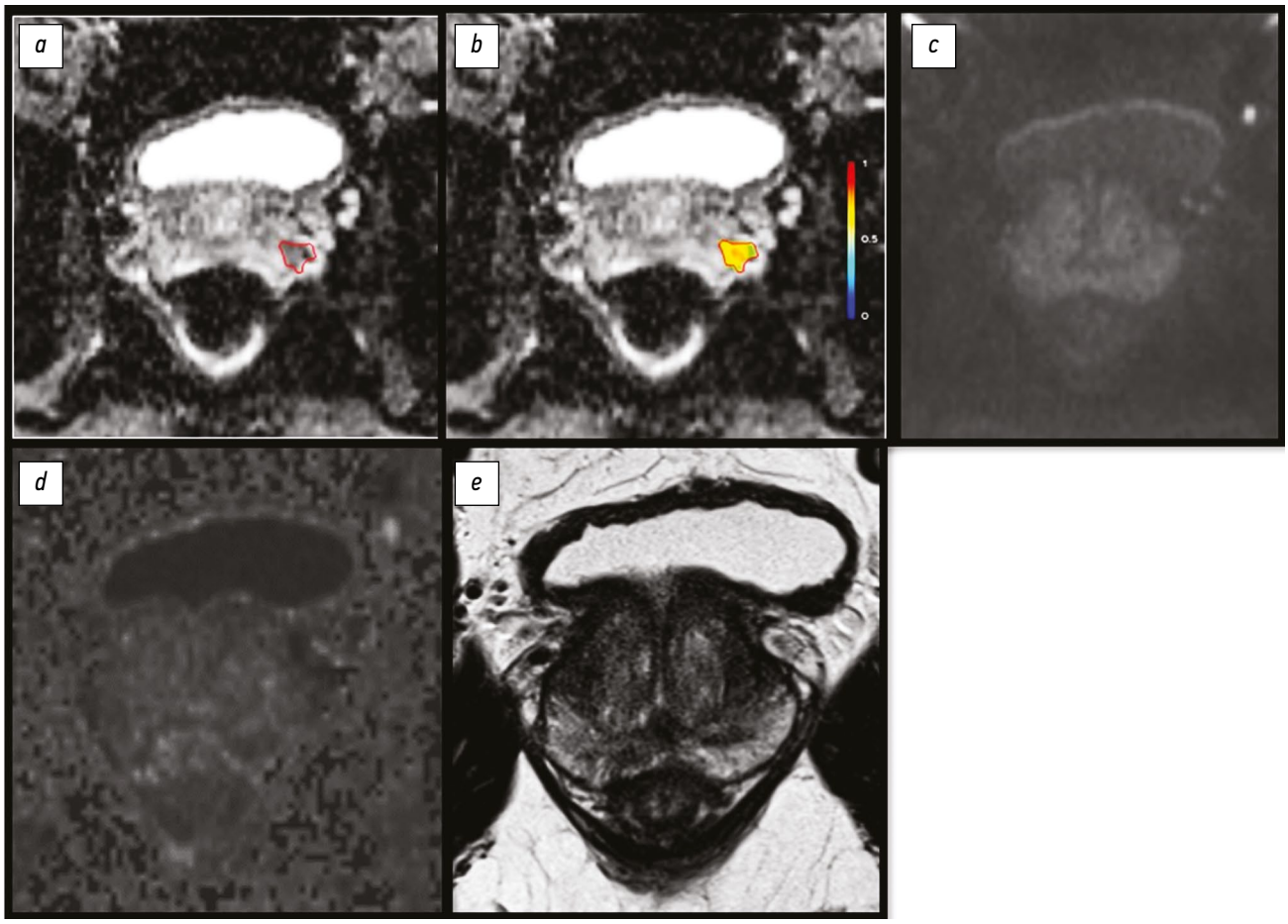

Fig. 2. Segmentation and evaluation of the entropy of the tumor focus of the transition zone of the prostate

Note. *a*, Map of the measured diffusion coefficient (MDC) of magnetic resonance imaging (MRI) of the prostate gland of a 65-year-old patient with a prostate tumor (Gleason 3 + 4) shows an area of reduced MDC (red outline; posterior segment of the transition zone of the middle part of the left lobe of the gland). Prostate biopsy performed 6 days after MRI; *b*, a heat map of a normalized textural characteristic (entropy); *c*, diffusion-weighted image (DWI), b-factor 900 mm/s^2, pathological focus is not visualized; *d*, DWI, calculated b-factor 1400 mm/s^2, pathological focus is not visualized; *e*, T2-weighted image, the pathological focus is not visualized.

selected clinicopathological predictors of histopathological progression in patients under active monitoring. However, none of the models under study has been implemented in routine clinical practice due to their low predictive accuracy. One possible explanation for this is the inherent difficulty in standardizing the predictors used, with an obvious example of the prostate-specific antigen density, which varies greatly depending on the imaging method used to measure the prostate volume [25]. In contrast, the ability of MRI to visualize the entire volume of the tumor, combined with ongoing attempts to standardize imaging parameters [26], is the basis for studying the ability of quantitative characteristics to act as accurate and reproducible predictors of disease progression.

In prostate cancer, a significant amount of research in the field of radiomics is aimed at improving the detection of a clinically significant disease [14, 27] to solve the problem of overdiagnosis of the latent oncological process [28]. Radiomics models have been developed for preoperatively predicting the probability of extracapsular extension [17, 29], which is important for accurate local staging of the disease and clinical decision making.

Methodological limitations of texture analysis

Retrospective studies are more prone to bias and confusion of variables, which can affect statistical processing and introduce errors in interpreting the results, leading to erroneous conclusions. The heterogeneity of studies makes ensuring reproducibility difficult, so large datasets are required to address this issue. E. Sala et al. [6] have recommended using informatics and analytics to form common datasets and ensure large sample sizes. In practice, this can be difficult to achieve due to data protection laws and infrastructure costs. Most studies conducted to date represent single-center pilot trials with small sample sizes and different methods of data collection and image texture analysis, which hinders the comparison of the results and explains the low reproducibility of the results.

A more significant problem is the imbalance of classes, that is, extracting more characteristics than the number of participants. Testing many textural characteristics requires statistical correction to eliminate the first-type error (false discovery). The use of complex regression models to search for significant characteristics increases the risk of data

oversampling [30]. Regression models may show effective results in one study but are unlikely to be replicated in other studies. Using only one textural characteristic per 10 patients in multiple regression models reduces the risk of overfitting in future studies.

The future of prostate cancer radiomics

Prostate radiomics is a rapidly developing field where early research was initially focused on tumor localization. A review of studies in the field of radiomics of the prostate gland enables the identification of patterns of development and promising fields of textural analysis. Let us consider three key aspects of the direction of development of prostate gland radiomics, namely, the aspects of data collection, their analysis, and the relationship with biological markers.

The use of radiomics in prostate cancer has evolved from macroscopic to microscopic levels. The highest stage in the development of radiomics is the individual prediction of the risks and results of treatment in a particular patient. An initial milestone is considered the study of MR spectroscopy in assessing the risk of biochemical recurrence after radiotherapy [31]. In their work, K. Gnep et al. [32] have revealed a relationship between the textural characteristics of Haralick according to multiparametric MRI of the prostate gland and the risk of biochemical recurrence after radiation therapy. The results have shown that the three textural analysis parameters calculated from T2-weighted images and MDC maps showed statistically significant correlations with biochemical recurrence rates [32]. In a study by S.B. Ginsburg et al. [33], this idea was developed in the form of the development of a multivariate logistic regression model using the parameters of T2-weighted images, where the described model reached an area under the receiver operating characteristic curve (AUC) of 0.83.

Several studies with a similar design, particularly the retrospective study by S.Y. Park et al. [34], have demonstrated the ability of MDC maps to predict biochemical recurrence after surgical treatment of prostate cancer (AUC = 0.76).

Radiomics research currently focuses mainly on lung cancer and neuroradiology; the number of prostate cancer studies is relatively small. However, it should be understood that most approaches for radiomic analysis under study in lung cancer can be applied to other oncological diseases.

Category 2 studies in the field of radiomics relate to the identification of relationships with histopathological parameters. A negative feedback between MDC and tumor aggressiveness, which is assessed using the Gleason scale, has been convincingly demonstrated [35]. An additional application of texture analysis parameters enables the development of prognostic models for assessing the degree of tumor malignancy, including the use of T2-weighted images [16, 23].

In some studies, a negative feedback was revealed between MDC and tumor cellularity [14]. However, most studies on tumor biology assessment remain at the correlation evaluation stage, and predictive models are only available for predicting tumor aggressiveness. The integration of radiomics and genetics has been named "radiogenomics," which is aimed at identifying the correlation between the quantitative indicators of a diagnostic image and the expression of specific tumor receptors [36]. Despite its relatively recent advent, several studies on radiogenomics have been conducted. Note that both quantitative indicators of multiparametric MRI and genetic information reflect the pathomorphological status of tumors.

In the study by N. Jamshidi et al. [37], the quantitative parameters of multiparametric MRI and genetic variants of intact tissue and tumor foci of the prostate gland were evaluated, and a relationship was revealed between quantitative markers of a diagnostic image and the genetic characteristics of the tissues.

In their study, R. Stoyanova et al. [38] have shown a significant correlation between some sets of genes and quantitative indicators of images, which enabled the distribution of patients into risk groups.

The research results demonstrated that radiogenomics can assess genetic characteristics that can be used to develop personalized tumor treatment strategies. Thus, current studies on prostate radiomics focus primarily on the histopathological level, with great prospects for tumor detection and aggressiveness stratification, whereas predictive models have yet to be developed for other biological characteristics of tumors.

CONCLUSION

The diagnosis of prostate cancer is currently based on a combination of histological data and medical imaging, primarily multiparametric MRI. Textural analysis can objectively, noninvasively stratify patients in terms of possible treatment options. Despite the limited number of studies, promising data have been obtained on the possibility of differential diagnosis of clinically significant prostate cancer, including the Gleason scale gradation.

Major prospective studies are required to implement radiomics into routine practice in the future.

ADDITIONAL INFORMATION

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Обзор российской нормативной документации по организации и функционированию кабинетов и отделений магнитно-резонансной томографии

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АННОТАЦИЯ

Диагностические исследования, проводимые с использованием какого-либо медицинского оборудования, нуждаются во всестороннем контроле, который обеспечивается рядом нормативных документов. Особенное внимание уделено рентгеновским методам визуализации, но в области магнитно-резонансной томографии можно заметить как недостаточность этого внимания, так и разнонаправленность усилий по нормированию.

Это объяснимо: в основе данного диагностического метода не используются источники ионизирующего излучения, а магнитные поля хоть и оказывают некоторое воздействие на здоровье человека, особенно на персонал, который работает в кабинетах магнитно-резонансной томографии постоянно, но являются относительно безопасными для пациентов, которые приходят на диагностическую процедуру время от времени и не имеют в своём теле инородных металлических (стальные имплантаты) или электронных (кардиостимуляторы, нейростимуляторы) изделий.

Тем не менее незнание и несоблюдение требований, которые носят как рекомендательный, так и обязательный характер, может значительно повысить риск причинения вреда пациентам или персоналу, а также привести к снижению качества визуализации и диагностики. Отдельная особенность сферы регулирования магнитно-резонансной томографии состоит в том, что за последние десятилетия было вновь издано либо пересмотрено более десятка различных стандартов, санитарных норм, правил, писем и рекомендаций, значительная часть которых дополняет или дублирует друг друга, либо противоречит другим документам. В результате сложно обеспечить соответствие кабинета магнитно-резонансной томографии требованиям нормативных документов.

В данной работе проведён обзор действующей на территории России нормативной документации, относящейся к организации и функционированию кабинета магнитно-резонансной томографии, выделены аспекты, наиболее важные с точки зрения безопасной и качественной эксплуатации, и сформулированы шаги, необходимые для модернизации системы как с точки зрения качества диагностики, так и безопасности диагностических исследований с применением ядерно-магнитного резонанса.

Ключевые слова: магнитно-резонансная томография; нормативы; медицинская организация; организация здравоохранения.

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The Russian regulatory documents on the organization and functioning of offices and departments of magnetic resonance imaging

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ABSTRACT

Diagnostic studies that are conducted using any medical equipment require comprehensive control, which is provided by several regulatory documents. Particular attention is paid to X-ray imaging methods, but in the field of magnetic resonance imaging, one can notice both the lack of attention and the multidirectional efforts for its normalization.

Understandably, this diagnostic method is not based on the use of ionizing radiation, and magnetic fields have some effect on human health, especially on personnel who work in magnetic resonance imaging rooms at all times. They are safe for patients who come to the diagnostic procedure from time to time and those without foreign metal (steel implants) or electronic (pacemakers and neurostimulators) objects in their bodies.

However, ignorance and non-compliance with both advisory and mandatory requirements can significantly increase the risk of harm to patients or staff, as well as lead to a decreased quality of imaging and diagnostics. A separate feature of the field of magnetic resonance imaging regulation in the past decades includes more than a dozen of different standards, sanitary norms, rules, letters, and recommendations that have been published or revised, of which a significant part complement or duplicate each other, or completely contradict each other. Therefore, the need to ensure the compliance of the magnetic resonance imaging room/department with the requirements of regulatory documents is greatly complicated.

This study provides an overview of the regulatory documentation in force in Russia related to the organization and functioning of a magnetic resonance imaging room/department, highlights the aspects that are most important from the point of view of the safe and high-quality operation, and formulates the steps necessary to modernize the system, both from the point of view of the quality of diagnostics and the safety of magnetic resonance imaging studies.

Keywords: magnetic resonance imaging; magnetic resonance imaging; organization and administration; practice guidelines as a topic.

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审查俄罗斯关于磁共振成像室和部门的组织和运作的监管文件

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简评

使用任何医疗设备进行的诊断研究都需要全面控制，这由许多监管文件提供。 特别关注X射线成像方法，但在磁共振成像领域，人们可以注意到缺乏这种关注和多方向的努力来规范化。

这是可以理解的：这种诊断方法的基础没有使用电离辐射源，虽然磁场对人体健康有一定的影响，尤其是对一直在磁共振成像室工作的工作人员，但对于那些在不时进行诊断程序，并且他们的体内没有外来金属（钢植入物）或电子产品（起搏器、神经刺激器）。

但是，无知和不遵守建议和强制性要求会显着增加对患者或工作人员造成伤害的风险，并降低成像和诊断的质量。 磁共振成像监管领域的另一个特点是，在过去几十年中，重新发布或修订了十多个不同的标准、卫生规范、规则、信函和建议，其中很大一部分相互补充或重复，或与其他文件相矛盾。因此，很难确保MRI室符合监管要求。

在本文中，我们回顾了俄罗斯现行的与磁共振成像室的组织和运作相关的监管文件，从安全和高质量操作的角度强调了最重要的方面，并制定了必要的步骤在诊断质量和使用核磁共振的诊断研究的安全性方面对系统进行现代化改造。

关键词：磁共振成像； 标准； 医疗机构； 医疗保健组织。

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INTRODUCTION

Instrumental diagnostics, involving the examination of patients using certain medical equipment, requires careful comprehensive control that must be specified in regulatory documents. To date, the requirements for X-ray imaging methods are the most complete. While in the field of magnetic resonance imaging (MRI), the requirements established are incomplete and inconsistent.

Unlike general radiography, computed tomography, mammography, and other methods involving the use of ionizing radiation, MRI is obtained due to exposure to magnetic fields, which does not induce obvious negative consequences to the human body. Thus, in our opinion, the regulatory system in this field has significant omissions, and the current regulations are based on the requirements for X-ray methods. Additionally, some documents are only advisory, leading to their complete disregard in practice. Failure to comply with certain mandatory conditions significantly increases the risk of harm to the health of patients or staff and decreases the quality of imaging and diagnostics.

Studies on some aspects within the life cycle of equipment, such as quality control, have been previously published [1]. Furthermore, methodological recommendations were developed based on the best international practices and related to the design [2] and operation of MRI rooms [3] and the labor protection of the medical personnel working there [4]; however, some significant steps were neglected.

Considering the recent adoption of several regulatory documents related to MRI, conveying information to medical organizations and proposing to introduce the standards into their activities are considered extremely important.

This study presents an overview of the regulatory documentation in Russia related to the organization and functioning of MRI rooms; emphasizes the aspects most important from the viewpoint of safe and high-quality operation; and develops the steps required to modernize the quality assurance system.

CURRENT REGULATORY BASE: CODE OF REQUIREMENTS FOR EQUIPMENT, ROOM, AND BUILDING

Apparatus selection

The application of the current regulatory framework can help choose an MRI unit. There are three state standards (i.e., GOST R 56310-2014 [5], GOST R 56320-2014 [6], and GOST R 56610-2015 [7]), which establish general requirements for preparing and executing technical specifications for state and municipal procurement of MRI units. These standards apply to MRI units with a constant magnetic field with a magnetic field induction B_0 of less than 0.75 T (GOST R 56320-2014) and superconducting coils B_0 of greater than 1 T (GOST R 56310-2014) for the entire body and less than 0.75 T and greater than 0.15 T for the limbs (GOST R 56610-2015). These documents, similar to other standards, are advisory and not binding.

Moreover, the classification and characteristics of some models of MRI units (mostly outdated at the moment) are given in the Information and Methodological Letter of the Federal Service for Supervision of Consumer Rights Protection and Human Welfare of 08/01/2007 N 9-05/122-486 (hereinafter Letter) [8].

Planning of MRI unit arrangement

After generating a medical and technical assignment at the stage of working with a potential supplier, one of the first tasks for medical organizations is most often the choice of a room to place the equipment. Simultaneously, depending on the functioning characteristics of a particular medical organization, the MRI room can be allocated as a separate structural unit or part of the Radiology Department (which is permitted by the Letter). The issue of the choice of premises is regulated by several regulatory documents.

Thus, according to cl. 4.3 of the Territorial Estimated Standards (TES) 31-313-98 of Moscow [9] and cl. 4.1.6 of the Sanitary Rules (SR) 2.1.3678-2020 [10], which were enforced on January 1, 2021, the building where the MRI room is planned to be located should not be residential or have a nonmedical purpose. Article (c) of cl. D.2.11 of Appendix D of SR 118.13330.2012 [11] and the section "Requirements for location and organization of work" of the Letter limit the choice of floor for the MRI room to the first floor, underground, or basement, while allowing its placement in an extension or a building specially constructed for this. In turn, according to the Letter and cl. 6.3.5a of SR 158.13330.2014 [12], considering the bearing capacity of floors is advisable when placing heavy equipment (in some cases, the weight of an MRI machine with all additional modules can reach tens of tons); therefore, these documents provide arguments for placing the MRI room in the basement/semibasement floor or on the first floor.

The intention and equipment of adjacent premises are the equally important selection factors. Clause 4.19.3 of SR 2.1.3678-2020 clearly prohibits the neighboring arrangement of an MRI room with wards for pregnant women, children, and cardiological patients and with 24-hour wards for patients. In adjacent premises, built in or attached transformer substations can never be located (cl. 7.7.1.5.3 of SR 158.13330.2014).

To avoid leaks, according to cl. 6.2.8 of the same rules (SR 158.13330.2014), choosing a room for an MRI unit under showers, lavatory, washing rooms, and other "wet places" is not recommended without additional waterproofing, and cl. 6.2.6 warns about the possibility of disruption of the equipment operation in the functional diagnostics rooms adjacent to the MRI room.

The control room (often referred to as the console room) should be located outside the controlled access area (cl. 4.19.5 of SR 2.1.3678-2020), which will be discussed in more detail in the "Physical factors" section. It must necessarily be a separate room with natural light, according to the "Requirements for location and organization of work" section of the Letter and cl. 71 of the rules for labor protection in medical organizations [13]. Simultaneously, cl. 4.6.2 in section SR 2.1.3678-2020 indicates that an MRI procedure room and a control room can be located in an area without sources of natural light, assuming that normalized microclimate indicators are provided, i.e., this set of rules contradicts itself.

According to the latest document, the appointment of patients in the control room is also forbidden; however, the procedure room (scanning room), according to cl. 5.14 of TES 31-313-98, should not have natural lighting.

Perhaps the least attention, in terms of layout, is given to the technical room of the MRI premises, which comprises the auxiliary equipment. According to the Letter, it should not be placed adjacent to the control room, the doctor's office, or patient wards. However, note that from the viewpoint of physical factors considered below, the requirements for these premises can be expressed more strictly.

Design (creation of an engineering project for an MRI room)

An engineering project is a document that describes the arrangement of equipment and the sequence of technological processes associated with its operation in the structure of a building under construction or in operation. However, in relation to MRI, most participants in the design and operation processes often have disagreements regarding the need to develop an engineering project.

Let us consider the current state of this issue.

The MRI room is part of a medical organization; therefore, its design must consider the requirements of the relevant rules of SR 158.13330.2014 regarding space-planning solutions for buildings (cl. 6.2.6), ventilation and air conditioning (cl. 7.2.3.3), minimum footage of premises (Table C.7), the degree of protection of lamps for general lighting of medical premises (Table P.1), and other aspects.

In contrast, according to cl. 3 of the Order of the Ministry of Health No. 560 dated June 9, 2020 [14], an MRI study is an X-ray examination; therefore, it must comply with the requirements of SanPiN 2.6.1.1192-03 [15]. Appendix 7 of these rules states that when the room commissioning agreed with the regional radiological department, a technological project must be submitted. Additionally, cl. 3.10 prohibits the use of the manufacturer's design proposal as a technological project, limiting the use of this document only to the choice of premises and their area.

The need for approval of the project for the MRI room was noted, among other things, in the Letter.

Composition and area of the MRI room

In addition to a careful approach to the placement of equipment to most effectively fulfill the target task of the MRI room, the functioning of such a structural unit involves several additional technological processes. These include preparing the patient for the study, inserting a catheter and performing other ancillary operations, reviewing the results of previous studies and completing a description of what has been performed, and communicating (questionnaire) with patients and their accompanying persons. However, during the interaction with the supplier in terms of preparing a floor plan for a technological project, the specifics of the work of a particular medical organization are often not considered.

The most effective approach for optimizing the space organization can be a clear description of the medical and technical assignment of all operations to be performed in the MRI room. In this case, the proposal for equipment arrangement and, thus, the project documentation, in addition to the established requirements of the equipment manufacturer, will meet the needs of the medical organization.

Furthermore, the current regulatory documentation introduced certain restrictions on the composition and area of the MRI room, while it is referred to both mandatory (i.e., SR 2.1.3678-2020, SR 158.13330.2014, and TES 31-313-98) and recommendatory (Letter) documents. A set of requirements for the composition and minimum area is presented in Table 1.

Note that the medical and technical assignment and technical documentation of the manufacturer may impose additional requirements on the minimum floor space relative to a particular MRI model.

Interior decoration of the MRI room

There are no special requirements for the MRI room in the regulatory documents in terms of interior decoration. The same provisions apply here that are relevant for all medical and diagnostic rooms with a dry regime and are presented in SR 158.13330.2014. Clause 6.4.2 states that the walls and ceilings are finished with acrylic or silicate water-soluble paints or other materials that allow wet cleaning and disinfection. The equipment attachment points, if it is placed on plasterboard walls or light partitions, should be further strengthened. This is consistent with the requirements of "SanPiN" 2.6.1.1192-03 (cl. 3.16).

Nevertheless, cl. 6.4.7 of SR 158.13330.2014 contains special instructions for radiation and radionuclide diagnostics and radiation therapy rooms regarding the floor, as it must consist of antistatic materials with a minimum number of joints between individual sheets of coating, or a jointless coating based on deactivated hardening compositions is permissible.

It is also appropriate to quote TES 31-313-98 of Moscow: "The interior decoration of the premises must be made of materials approved by the authorities and institutions of the Department of State Committee for Sanitary and

Table 1. Requirements of regulatory documentation for the composition and minimum area of the premises of the magnetic resonance imaging room

MRI room	Minimum area, m^2			
	SR 2.1.3678-2020	TES 31-313-98	SR 158.13330.2014	Letter
Procedure Diagnostic room	Manufacturer's sp.	42	25	40–46* (but not less than 12)
Control (console) room	8	20	10	14–17
Technical (apparatus) room	-	20*	20	20–24
Doctor's office	-	12	-	12
Preparatory room	4	10	12	-
Dressing room	-	-	-	Availability
Toilets for staff and visitors	-	-	-	3 × 2**
Photolaboratory (photo) room	-	10	-	10**
Engineer's room	-	10	-	-
Staff room	-	-	-	12

Note. *Area subject to change; **if necessary, can be displaced from the MRI room. MRI–magnetic resonance imaging; Sp–specifications; SR–sanitary rules; TES–Territorial Estimated Standards.

Epidemiological Oversight of the Ministry of Health of the Russian Federation, and correspond to their functional purpose" (cl. 5.16).

Physical factors

Most requirements in the current regulatory documentation are imposed on working conditions and physical factors affecting staff and patients, both in general terms and directly in relation to MRI. Harmful factors in the MRI room can include a constant magnetic field (directly at the device when laying the patient and working with radiofrequency coils), the risk of infection transmission, a high level of workload and intensity, insufficient illumination, and pulsation of the light flux. Simultaneously, according to SanPiN 1.2.3685-21 [16], the compliance of the microclimate parameters with the hygienic standards of physical factors in the workplace should be assessed. In the current regulatory documentation, the requirements for these parameters are presented separately.

The operation of MRI assumes the presence of magnetic fields that are constant and variable in time and space (GOST R IEC 60601-2-33-2013), whereas, in the most common version, an MRI unit with a superconducting magnet, a constant magnetic field is not deactivated unless an emergency occurs, and variable fields are used only when performing a scan and obtaining an image. To reduce the negative impact on personnel, SanPiN 1.2.3685-21 establishes the maximum permissible levels of constant magnetic fields (Table 5.8) and electromagnetic fields of industrial frequency (Table 5.41). Similarly, the Letter introduced the intensity of a constant magnetic field at workplaces (Table 2) and the electromagnetic field of a personal electronic computer at workplaces (Table 3) [8].

GOST R of the International Electrotechnical Commission (IEC) 60601-2-33-2013 (cl. 201.7.9.3.101) introduces the concept of a controlled access area limited by an induction isoline of a constant magnetic field corresponding to 0.5 mT, whereas the level of the electromagnetic field inside the controlled access area must comply with GOST IEC 60601-1-2-2014. The control room should be located outside the controlled access area; however, if the zone of the line of the controlled access area extends to areas of adjacent premises, strict control and restriction of access of patients and personnel with pacemakers and other types of implanted electronic stimulators is required (cl. 4.19.5, 4.19. 7 SR 2.1.3678-2020). According to the rules for labor protection in a medical organization (cl. 70), as well as cl. 4.19.4 of SR 2.1.3678-2020, both the controlled access area and the MRI room are supposed to be marked with warning signs.

The procedure, control, and preparatory rooms and the doctor's office, which are part of the MRI room, belong to the premises for the performance of work and, therefore, are subject to the requirements of SR 2.1.3678-2020 in terms of microclimate and ventilation. So, according to cl. 4.5.16, the premises of the MRI room must be equipped with supply and exhaust ventilation, and Appendix 3 introduces the requirements for the cleanliness class, temperature, and air exchange, while natural air exchange is not allowed (this requirement is duplicated in clause 7.2.3.3 of the SR 158.13330.2014).

Additionally, the Letter regulates the temperature, air velocity and relative humidity, the rate of air exchange for supply and exhaust, the category of cleanliness, and the rate of exhaust during natural air exchange [8].

Therefore, the requirements of different documents differ to some extent. Their summary is presented in Table 2.

Note that the temperature and humidity in the procedure and technical rooms are critical parameters for ensuring the normal functioning of the equipment. Thus, manufacturers accompany the installation of a ventilation

Table 2. Requirements for the microclimate and ventilation of the premises of the magnetic resonance imaging room

Requirements	SR 2.1.3678-2020	SR 158.13330.2014	Letter
Procedure (diagnostic) room			
Cleanliness class (category)	V	G	Ch
Temperature, °C	20–23	-	22
Air exchange (supply/exhaust), %	100/100 Oxygen content ⩾18%	3/4	2/2
Control (console) room			
Cleanliness class (category)	G	G	Ch
Temperature, °C	18	-	20
Air exchange rate (supply/exhaust)	3/4	3/4	-/1
Technical (apparatus) room			
Cleanliness class	-	-	-
Temperature, °C	-	-	-
Air exchange rate (supply/exhaust)	-	-	-
Doctor's office			
Cleanliness class	G	-	Ch
Temperature, °C	20	-	20
Air exchange rate (supply/exhaust)	60 m^3 per person	Supply	-/1
Preparatory (dressing) room			
Cleanliness class	G	-	-
Temperature, °C	20	-	-
Air exchange rate (supply/exhaust)	From corridor/1	3/-	-
Toilet			
Cleanliness class	G	D	G
Temperature, °C	20	20–27	20
Air exchange rate (supply/exhaust)	Exhaust	Exhaust	Exhaust
Staff room			
Cleanliness class	G	-	Ch
Temperature, °C	20	-	20
Air exchange rate (supply/exhaust)	From corridor/1	-/1	-/1

and air conditioning system with additional requirements for the microclimate.

To ensure comfortable work (especially when precise manipulations are required), all cabinet rooms must have high-quality artificial lighting, while both the illumination itself and the pulsation coefficient are normalized. The set of requirements of SanPiN 1.2.3685-21 (Table 5.54) and the Letter (Table 8) is presented in Table 3.

During the operation of an MRI unit, a sufficiently high level of acoustic noise is created. Simultaneously, as mentioned above, the most common MRI units with a superconducting magnet always work (to maintain superconductivity), and additional modules (gradient coils, radiofrequency coils, etc.) are activated during scanning, which increases the noise level. The maximum sound pressure level largely depends on the model and conditions of use of the MRI and, in some cases, can exceed 100 dBA. Thus, to ensure normal working conditions, soundproofing should be provided in the MRI room and adjacent premises.

The maximum permissible noise levels in the office premises are presented in Table 5.35 of SanPiN 1.2.3685-21 and Tables 4–7 of the Letter. The requirements in these documents are identical, except for the discrepancies in classifying a particular room as one or another category (e.g., in terms of areas where medical activities are performed).

Additionally, these regulatory documents impose requirements on sound pressure levels in octave frequency bands and a general limit on the noise produced by the equipment (140 dB relative to the level of 20 μPa according to cl. 201.9.6.2.1 GOST R IEC 60601-2-33-2013 [17]).

Electrical and fire safety

Considering the inclusion of MRI in the list of X-ray examinations, the equipment located in the office is subject to SanPiN 2.6.1.1192-03, according to which the power supply of the MRI unit must be implemented through a separate feeder (cl. 10.9), and grounding is performed along

Table 3. Requirements for illumination in the rooms of the magnetic resonance imaging unit.

Premises	Working plane and height above the floor*, m		Artificial illumination			
			Illumination under general lighting, lx		Ripple coefficient, %	
	SanPiN 1.2.3685-21	Letter	SanPiN 1.2.3685-21	Letter	SanPiN 1.2.3685-21	Letter
Procedure room	H-0.8	H-0.8	300 (**500)	500***	15 (**10)	10
Control room	H-0.8	-	300	-	15	-
Patient preparatory room	H-0.8	-	75	-	-	-
Dressing room	H-0.0	-	200	-	-	-
Doctor's office	H-0.8	-	300	-	15	-
Staff room	H-0.8	-	300	-	15	-
Toilets	H-0.0	H-0.0	75	50	-	-

Note. *H–horizontal; **during intravenous manipulations; ***in this section, requirements are made for the procedure and diagnostic rooms (what is meant by the latter is unclear).

an autonomous circuit with a bus with a cross-section of at least 4 × 25 mm (cl. 10.5).

According to GOST R 50571.28-2006 [18], the MRI room can be assigned to the safety group 1, and therefore, using a backup power source and signal notification of switching to it becomes necessary. Note that an uninterruptible power supply source is a mandatory component of the MRI unit with a superconducting magnet.

Fire safety requirements are established in GOST 12.1.004-91 [19], according to which, in relation to the MRI room, the level of fire safety should be determined (Appendix 2), the probability of fire and explosion should be determined (Appendix 3), and the economic efficiency of the fire safety systems should be assessed (Appendix 4). Moreover, note that the installation of fire alarms and fire extinguishing systems in the procedure room is difficult, and therefore, smoke and gas sensors are installed on the exhaust ventilation. Fire extinguishing equipment must be MRI compatible [4].

Operation

As a medical product, an MRI unit must undergo mandatory maintenance and technical condition control. According to the Letter of the Ministry of Health of the Russian Federation No. 293-22/233 dated October 27, 2003 [20], the list of works within the maintenance is established by the methodological recommendations "Maintenance of medical equipment" and includes installation and adjustment, monitoring of the technical condition, periodic and current maintenance, and repair of medical equipment.

In turn, GOST R 56606-2015 [21] defines a list of tests performed within the technical condition control, namely, acceptance and periodic tests and tests for the constancy of parameters. Test methods and the requirements for equipment and conditions for their implementation are presented in GOST R 59092-2020 [22].

Additionally, there are local provisions; for example, in Moscow, the order of the Moscow Health Department No. 564 of August 17, 2018 was approved [23], which regulates the storage, installation, use, operation, maintenance, repair, and disposal of medical equipment.

The requirements for ensuring the safety of personnel while working in the MRI room are set in Section IX of the Rules for Occupational Safety in a Medical Organization [13]. First, its requirements limit the exposure time of personnel to magnetic fields. Simultaneously, rather ambiguous requirements have been introduced; that is, the laying of the electromagnet power cable is regulated and the duty of the staff to check the connection of the ground loop and the prohibition of leaving the MRI unit turned on unattended.

FACTORS HINDERING THE USE OF THE REGULATORY FRAMEWORK

Thus, we are faced with a whole list of regulatory legal acts in terms of the use of MRI, approved over the past decades. Unfortunately, a significant part of them was formulated based on similar documents for medical ionizing radiation equipment or introduced point limitations, often taken from international sources. Therefore, the procedure for ensuring the compliance of the MRI room with the requirements of regulatory documents and standards is complicated by the inconsistency, incompleteness, and sometimes contradiction of the information provided.

The obvious factors complicating the use of the existing regulatory framework include the lack of a systematic approach and unified terminology, duplication (often with amendments) of requirements for the same parameters, and, most importantly, "white spots" covering a significant part of the equipment commissioning and operation stages. Certainly, a qualified reader can easily compare the "diagnostic room" and "procedure room" or determine the intention of the "computer room" and "photolaboratory" in the MRI room. However, industry or sanitary standard formats suppose a slightly different approach.

The discrepancy not only in the ranges of permissible values but also in the list of requirements presented in the

regulatory documentation, on the one hand, and the technical documentation of manufacturers or recommendations from specialized professional communities, on the other hand, are also noteworthy.

Let us consider the measurement of the air exchange rate in the procedure room of the MRI premises as an example. So, in the documentation, when rationing the air supply and exhaust, the oxygen content, and the frequency of monitoring these parameters, the fact that the market offers no MRI compatible devices that allow such functions is completely not considered. In most cases, the efficiency of the ventilation system primarily affects the equipment performance; therefore, taking care of the comfort of patients in the presence of a malfunction is only senseless, and the equipment operation should be stopped. Simultaneously, the regulatory documentation almost completely ignores the emergency ventilation system, which directly affects the safety of MRI operation.

The requirements governing the placement of the control room outside the controlled access area are not often feasible (its boundaries can only be determined at the final stage of putting the MRI unit into operation after the measured contour map has been created).

A more general problem arises at the office design stage. Unfortunately, practice has revealed the complete failure of the developed medical and technical assignment and the engineering project created on their basis. Thus, the analysis of the documentation for some already functioning MRI rooms has shown that ignoring the obvious requirements for patient flow and equipment loading and the descriptions of technological processes in the medical and technical assignment with a design based only on the manufacturer's suggestion for arranging the equipment and the most general layout of the room significantly decreases the efficiency of the department and the complete impossibility of performing part of the manipulations.

The requirements for arranging a room for performing the interview, anthropometry, and examination of patients for the presence of metal and shifting of bedridden patients from a standard to an MRI-compatible couch or chair are not regulated in any way. This leads to the fact that these actions are performed in a common corridor where patients are awaiting their appointment, and anthropometry and detection are not performed at all.

Therefore, important security requirements, such as restricting access, are not executable. Staff may experience difficulty in transporting sedentary patients and be forced to ignore important, from the viewpoint of safety, stages of preparation for the study.

Discussing about ensuring the safety and quality of MRI, we must state the complete unsystematic nature of the requirements. Although attempts are being made to develop methodological recommendations and educational programs, only a few points are found in the regulatory documentation. Moreover, the attempts of a medical organization to directly fulfill the contradictory requirements are reminiscent of the attempts to squeeze into the "needle eye."

CONCLUSION

The efficient and safe operation of MRI rooms requires careful and consistent work in extensive cooperation with the medical community, equipment manufacturers, regulatory authorities, and metrological institutions. Simultaneously, standardization and unification and systematization and widespread implementation of the procedure for monitoring the implementation of the requirements introduced should be the priority fields of interaction.

ADDITIONAL INFORMATION

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Перфорация дивертикула Меккеля у молодого пациента: клинический случай

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АННОТАЦИЯ

В данной статье описывается случай перфорации дивертикула Меккеля у 26-летнего пациента. Это редкое осложнение, возникающее при наиболее распространённой врождённой аномалии желудочно-кишечного тракта. Дивертикул Меккеля может долгое время протекать бессимптомно и осложняться дивертикулитом, энтеролитами, новообразованиями и реже, как в нашем случае, перфорацией.

Для постановки правильного диагноза и последующего лечения пациента решающее значение имеет рентгенологическое исследование в предоперационном периоде.

Представленные в статье типичные особенности перфорации дивертикула Меккеля, выявляемые при томографической визуализации, помогут рентгенологам в обнаружении этого осложнения.

Ключевые слова: дивертикул Меккеля; перфорация; врождённый порок развития; компьютерная томография; визуализация органов брюшной полости; клинический случай.

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Perforated Meckel's diverticulum in a young male patient: a case report

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ABSTRACT

The case of a 26-year-old male patient with perforation of Meckel's diverticulum, a rare complication of the most common congenital anomaly of the gastrointestinal tract, is reported in this article. This congenital condition can remain asymptomatic for a long time, and it can get complicated with diverticulitis, enteroliths, neoplasms, and rarely perforation, as in this case.

A preoperative radiological assessment is of fundamental importance for proper diagnostic and therapeutic management of the patient. In this article, we present the typical tomographic imaging features of this infrequent complication to assist radiologists in detecting it.

Keywords: Meckel's diverticulum; perforation; congenital malformation; computed tomography; abdominal imaging; clinical case.

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年轻男性患者梅克尔憩室穿孔：一份病例报告

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摘要

本文报告了一例26岁男性梅克尔憩室穿孔患者，这是最常见的胃肠道先天性异常的一种罕见并发症。这种先天性疾病可在很长一段时间无症状，并可并发憩室炎、肠结石、肿瘤和罕见的穿孔，如本例所示。

术前放射评估对于患者的正确诊断和治疗管理至关重要。在本文中，我们介绍了这种罕见并发症的典型断层成像特征，以帮助放射科医生发现这种疾病。

关键词：梅克尔憩室；穿孔；先天畸形；计算机断层成像；腹部显像；临床病例。

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DESCRIPTION OF THE CASE

Anamnesis. A 26-year-old male patient was admitted to our emergency department due to severe abdominal pain, fever, and vomiting, with vital signs in a normal range.

Diagnostic assessment. The physical examination demonstrated a distended abdomen with guarding and rigidity.

Blood analysis revealed neutrophilic leukocytosis, with a white blood cell count of 12,000/μl (normal values: 4.6–10.2 × 10^3/mL) and approximately 70% of neutrophils (normal values: 40%–75%).

Subsequently, further instrumental investigations were recommended: abdominal X-rays, chest X-rays (which were unremarkable) and finally a total body computed tomography (CT).

On pre-contrast CT evaluation, a blind-ended intestinal loop in the right quadrants of the abdomen was identified, which was associated with diffuse mesenteric edema and multiple contiguous lymphadenopathies (Fig. 1*a*, *b*); a post-contrast CT was performed a few hours later, which showed an intense contrast enhancement of the intestinal wall at the level of the blind-ended loop.

These findings were associated with the presence of certain adjacent gas nuclei with antideclive arrangement, diagnostics for perforation (Fig. 2*a*, *b*).

The differential diagnosis. Such characteristics often simulate acute appendicitis, the main condition to be placed in differential diagnosis of Meckel's diverticulum (MD) inflammation. The identification of a normal appendix strengthens the confidence of the diagnosis.

Interventions. No other examinations were performed and the patient was taken to the operating theater. During the surgery was made definitive diagnosis of Meckel's diverticulitis and for this reason the patient was subjected to Meckel's diverticulectomy and ileostomy surgery under general anesthesia.

Follow-up and outcomes. The patient recovered without any complication and was discharged after a couple of days of hospitalization.

DISCUSSION

MD is the most common congenital malformation of the gastrointestinal tract, affecting 2% of the population and carrying a 4.2%–6.4% risk of complications [1]. It was initially reported in 1809 by a German anatomist, Johann Meckel [2], and it is caused by improper closure and absorption of the omphalomesenteric duct [3], the original communication point between the yolk sac and the intestinal lumen in embryonic life, which generally closes around the ninth week of gestation. It frequently contains heterotopic mucosa, such as gastric and pancreatic mucosa, can cause peptic ulceration within the diverticulum or adjoining ileum as a result of their secretions, resulting in intestinal hemorrhage, cicatricial stenosis of the diverticular neck, inflammation, and even perforation.

The well-known "rule of 2s" in the description of this pathology refers to its 2% prevalence, 2-ft distance from ileocecal valve, 2-inch long, containing one or two types of heterotopic gastric or pancreatic tissue, and usually symptomatic by the age of 2 years [4].

The radiological diagnosis of MD can be difficult, especially if the diagnosis is not suspected at first due to the typical nonspecific symptoms of appendicitis, such as abdominal pain, vomiting, and nausea.

CT is now the method of choice, as well as the most accurate, in the evaluation of abdominal pathologies in emergency.

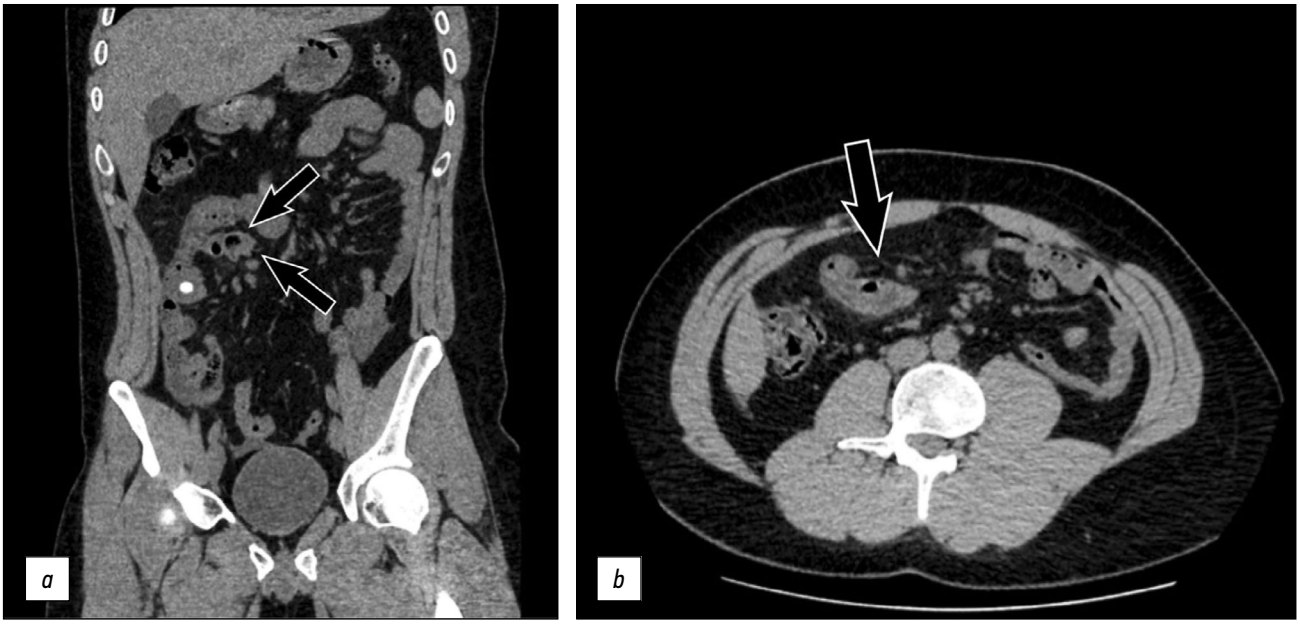

Fig. 1. This coronal (*a*) and axial (*b*) pre-contrast computed tomography images showing a blind-ended intestinal loop (arrows) in the right quadrants of the abdomen with associated mesenteric edema and multiple contiguous lymphadenopathies.

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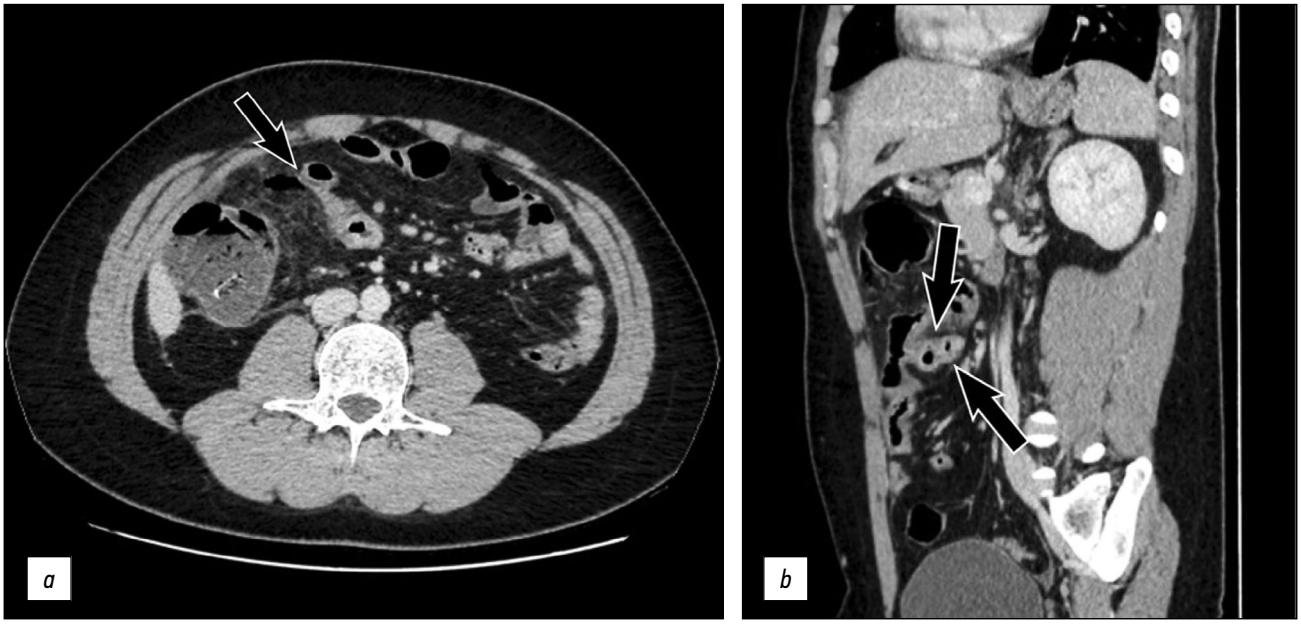

Fig. 2. Axial (*a*) and sagittal (*b*) post-contrast computed tomography images showing an intense contrast enhancement of the intestinal wall at the level of the same blind-ended loop (arrows) and some adjacent gaseous nuclei with antideclive arrangement, diagnostic for perforation.

MD generally appears on CT as a blind-ended gas- or fluid-filled structure, which may also contain foreign bodies or enterolithis, generally about 60 cm away from the ileocecal valve. This imaging technique is also able to detect the main complications of this malformation, such as perforation, in this case.

While definitive surgery, including diverticulectomy, wedge, and segmental resection performed by open or laparoscopic approach, is used to treat symptomatic MD, the surgical management of MD accidentally remains controversial [5].

CONCLUSION

MD can present with a wide range of clinical manifestations and imaging features, from indolent benign findings to acute life-threatening conditions, such as its perforation, as in the case presented here [6]. This is the fundamental reason why it is necessary to know its salient anatomy, clinical, and imaging features in order to allow an early radiological diagnosis and a prompt intervention.

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Authors' contribution. Tupputi Umberto and Carpagnano Francesca Anna have done the research work related to the topic and the manuscript writing; Carpentiere Rossella and Giuseppe Guglielmi have made the clinical decision of the case and have helped to draft the manuscript. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Consent for publication. Written consent was obtained from the patient for publication of relevant medical information and all of accompanying images within the manuscript.

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Инкапсулированный некротический панкреатит

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АННОТАЦИЯ

Некротический панкреатит, или панкреонекроз, — наиболее тяжёлая форма острого панкреатита с высокой частотой летальных исходов. Период, наиболее подходящий для диагностики острого панкреатита, составляет 3–5 дней от манифестации симптомов болезни. В этот период отёк и преходящая ишемия поджелудочной железы могут маскироваться под некроз и разрешаться при последующих исследованиях, и наоборот, местные осложнения могут развиваться без клинических корреляций.

В настоящее время при ведении острого панкреатита все большее значение отводится методам лучевой диагностики, в частности компьютерной томографии, за счёт возможности более точной волюметрии поджелудочной железы, оценки состояния и измерения диаметра селезёночной вены, что в перспективе может иметь значение при формировании прогноза течения панкреонекроза.

В статье приведён редкий клинический случай осложнения острого панкреатита — инкапсулированного некротического панкреатита, возникшего на фоне алиментарных нарушений. Приведены аспекты семиотики лучевых методов диагностики при динамическом обследовании данных патологий. Случай примечателен тем, что манифестация заболевания у пациента при поступлении в стационар была сопоставима с классической отёчной формой острого панкреатита. Дальнейшее нарастание отрицательной динамики было отмечено серией компьютерно-томографических изображений в динамике, выполненных между клинико-морфологическими фазами течения острого панкреатита и до формирования панкреонекроза, осложнённого секвестрацией тела поджелудочной железы с парапанкреатическим абсцедированием, что позволило максимально наглядно показать ступенчатое развитие заболевания. Лечебная парадигма была изменена, и место консервативного подхода заняла активная хирургическая тактика с последующими неоднократными манипуляциями и динамическим компьютерно-томографическим и магнитно-резонансным контролем вплоть до улучшения состояния пациента.

На сегодняшний день методы лучевой диагностики в совокупности с адекватным терапевтическим и хирургическим подходами способны улучшить прогноз течения некротического панкреатита.

Ключевые слова: мультиспиральная компьютерная томография; МСКТ; магнитно-резонансная томография; МРТ; компьютерная томография; КТ; некротический панкреатит; панкреатит; поджелудочная железа; панкреонекроз; клинический случай.

Как цитировать

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Encapsulated necrotic pancreatitis

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ABSTRACT

This study presents a rare clinical case of encapsulated necrotic pancreatitis, which was a complication of acute pancreatitis that arose against the background of alimentary disorders. The aspects of the semiotics of radiation diagnostic methods in the follow-up control of these pathologies were presented.

This case is notable for the manifestation of diseases upon hospital admission, as in the classical edematous form of acute pancreatitis, with a further increase in negative dynamics. This demonstrated the possible stepwise disease development, accompanied by a series of follow-up computed tomography between the clinical and morphological phases of acute pancreatitis and before the formation of pancreatic necrosis, which was complicated by sequestration of the pancreatic body with peripancreatic abscess formation. Afterward, the therapeutic paradigm was changed, and the place of the conservative approach was taken by active surgical tactics, followed by repeated manipulations and follow-up computed tomography and magnetic resonance until the improvement of the patient's condition.

Keywords: multispiral computed tomography; MDCT; magnetic resonance imaging; MRI; computed tomography; CT; necrotic pancreatitis; pancreatitis; pancreas; pancreatic necrosis; case report.

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包裹性坏死性胰腺炎

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简评

坏死性胰腺炎或胰腺坏死是急性胰腺炎中最严重的一种，死亡率很高。最适合诊断急性胰腺炎的时期是从疾病症状开始的3–5天。在此期间，胰腺水肿和暂时性缺血可能伪装为坏死，并在后续研究中消失，反之亦然，局部并发症可能在没有临床相关性的情况下发生。

目前，在急性胰腺炎的治疗中，放射诊断方法越来越受到重视，尤其是计算机断层扫描，因为它可以更精确地测量胰腺容积、评估病情和测量脾静脉直径，这在未来可能对胰腺坏死过程的预后形成有重要影响。

这篇文章介绍了一个罕见的急性胰腺炎并发症的临床病例包裹性坏死性胰腺炎，它是在消化系统疾病的背景下出现的。本文介绍了放射诊断方法在这些病理学动态检查中的符号学方面。该病例值得注意的是，患者入院时的疾病表现与典型水肿型急性胰腺炎相当。在急性胰腺炎病程的临床和形态学阶段之间以及在胰腺坏死形成之前进行的一系列动态CT图像显示负动态进一步增加，并伴有胰腺体分离和胰旁脓肿形成，这使得最清楚地显示疾病的逐步发展成为可能。治疗模式发生了改变，保守治疗被积极的手术策略所取代，随后是反复操作、动态计算机断层扫描和磁共振控制，直到患者病情好转。

迄今为止，放射诊断方法结合适当的治疗和手术方法可以改善坏死性胰腺炎的预后。

关键词： 多层计算机断层扫描；MSCT；磁共振成像；核磁共振；CT扫描；电脑断层扫描；坏死性胰腺炎；胰腺炎；胰腺；胰腺坏死；临床病例。

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INTRODUCTION

The most severe form of acute pancreatitis is necrotic pancreatitis, which has a mortality rate ranging from 30% to 100% [1–4]. Necrotic pancreatitis, also known as pancreatic necrosis, occurs in 15%–20% of cases of acute pancreatitis [5]. The global incidence of acute pancreatitis ranges from 4.9 to 73.4 cases per 100,000 populations, with 10%–13% of patients with abdominal surgical pathology in Russia [6].

The key importance of radiodiagnostic methods for detecting the disease and selecting the approach to managing patients with pancreatic necrosis has been described by major Russian scientists [7], as well as a number of international authors [8–11].

Currently, the role of radiation diagnostic methods in the management of acute pancreatitis, in particular computed tomography (CT), is expanding due to the possibility of more accurate volumetry of the pancreas [12], assessment of the condition, and measurement of the diameter of the splenic vein, which may be important in the formation of the prognosis of pancreatic necrosis course [13]. The first studies are being conducted to investigate the relationship between the loss of skeletal muscle density according to CT data and the deterioration of the prognosis of the course of necrotic pancreatitis [14].

The updated Atlanta guidelines on the course and management of acute pancreatitis (USA, 2012)[1] include trends to reduce radiation exposure to the patient and reduce the economic burden by refusing excessive imaging (CT and MRI) with a primary reliance on clinical examination data, ultrasound (US), and biochemical markers of inflammation; exceptions include an unclear diagnosis or aggravation of the condition in acute pancreatitis during the first 48–72 hours [15, 16]. However, other sources indicate that more than half of patients with acute pancreatitis who are clinically suitable for curation without objective imaging methods do so on their own [17]. When using updated diagnostic criteria to make clinical decisions, physicians experience additional stress [18]. Over time, the Atlanta classification for acute pancreatitis has been revised and is now widely used in Europe [19].

CASE DESCRIPTION

On January 13, 2018, patient Kh., 40, was admitted to the intensive care unit in a critical condition with a clinical presentation of acute pancreatitis and multiple organ failure, as well as complaints of severe girdle pain in the upper abdomen, nausea, and vomiting upon admission.

Case history. The patient experienced an acute onset of the disease within a day of eating a large amount of fatty foods (hypersecretory mechanism of development); in the morning, he experienced stabbing pains in the upper abdomen, followed by nausea, vomiting, and pain radiation to the lumbar region. He was taken by an ambulance to the admission department of the National Medical Research Treatment and Rehabilitation Center of the Ministry of Health of Russia (Moscow).

Results of physical, laboratory, and instrumental examination

At the time of admission, the patient's condition was classified as early phase IA.

A multispiral CT on January 14, 2018, revealed acute pancreatitis with no signs of destruction of the pancreatic parenchyma (Fig. 1).

Within 2 days in the intensive care unit, the patient underwent infusion-corrective, antisecretory, antioxidant, hepatoprotective, and antispasmodic therapy; multimodal anesthesia was administered, as well as prevention of thromboembolic complications and decompression of the gastrointestinal tract.

On January 15, 2018, the patient with subjective improvement was transferred to the department. When a fever of up to 38°C appeared, antibiotics were added to the treatment. A dense painless infiltrate 12 × 10 cm in size was palpated in the paraumbilical region on the left by the clinician. Clinically, the situation was regarded as a manifestation of acute pancreatitis phase IB (the phase of formation of peripancreatic infiltrate and resorptive fever).

By January 22, 2018, after the patient's condition had stabilized, his body temperature had returned to normal and data from laboratory and instrumental studies had been collected, there was an increase in signs of local inflammatory changes in the retroperitoneal space. The US results showed an increase in the volume of fluid in the abdominal cavity as well as imbibition of fatty tissue in the left half of the retroperitoneal space (pancreatic necrosis).

The study was supplemented with CT scans of the thoracic organs (TO CT) and the abdominal organs (AO CT), which revealed bilateral pleural effusion, with more on the left; consolidation in the lower lobe of the left lung; atelectasis in the basal sections of both lungs; and destructive pancreatitis with the pancreatic parenchyma contrasted fragmentarily, its head increased over time, increased fluid accumulations and the appearance of heaviness in the abdominal cavity and retroperitoneal space (Fig. 2). The changes allowed for an evaluation of the clinical and instrumental presentation at the phase IB end and the phase II beginning of the disease (aseptic sequestration).

Given the absence of signs of pancreatic tissue infection in the patient and clinical improvement, it was decided to forego surgical intervention. By January 24, 2018, the general blood test showed a decrease in leukocytosis (from 21.8 to 16.9 × 10^9 g/l) and C-reactive protein (from 206 to 144 ml/l) concentrations. However, after a period of clinical

[1] Atlanta classification of acute pancreatitis. Access mode: https://medach.pro/post/1830. Reference date: 10/15/2021

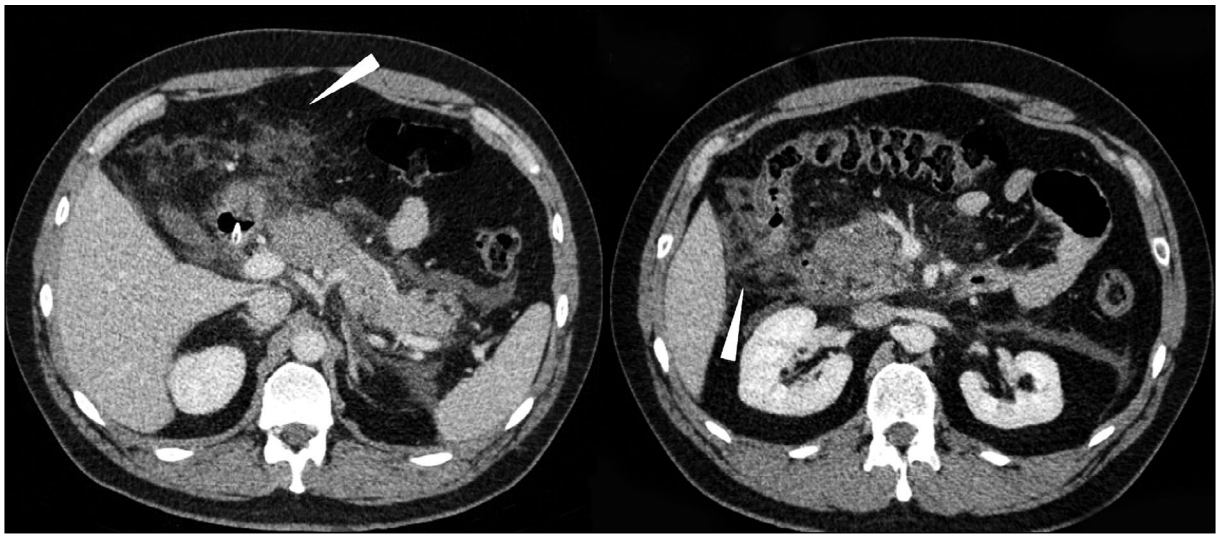

Fig. 1. Computed tomography of the abdominal organs with intravenous contrasting: infiltration of peripancreatic adipose tissue and adipose tissue in the subhepatic space (arrows)

improvement, on day 18 of admission (January 31, 2018), the patient's condition deteriorated sharply, with the appearance of pain, hyperthermia up to 38°C with chills, equivocal peritoneal symptoms, and an increase in leukocytosis up to 31×10^9 g/l in the general blood test.

The control ultrasound of the abdominal cavity detected sequestration of the gland body and the accumulation of a large amount of fluid around it; fenestration of the omental sac with the abdominal cavity, where an undelimited liquid with fibrin inclusions (at least 1 liter in volume) is also found in all departments; and pronounced imbibition of the retroperitoneal fatty tissue of the paracolar zones. Thus, the ultrasound presentation corresponded to the progression of necrobiotic changes in the pancreas due to pancreatic necrosis, i.e., and the formation of a parapancreatic abscess.

On January 31, 2018, after a brief preoperative period, diagnostic laparoscopy, sanitation, and drainage of the abdominal cavity were performed urgently, followed by conversion to laparotomy with the formation of an omentobursostomy in order to facilitate access to the omental sac for necrosequestrectomy.

The intraoperative diagnosis was severe acute pancreatitis, pancreatic necrosis with retroperitoneal fluid accumulations, phase of septic sequestration, and widespread pancreatogenic serous-fibrinous (enzymatic) peritonitis.

On February 1, 2018, an ultrasound of the abdominal cavity revealed a fluid accumulation of 7 × 4.5 × 15 cm in the right half of the retroperitoneal space, closely adjacent to the posterior wall of the ascending colon. Due to the high risk of damage to the colon during open drainage, US-controlled

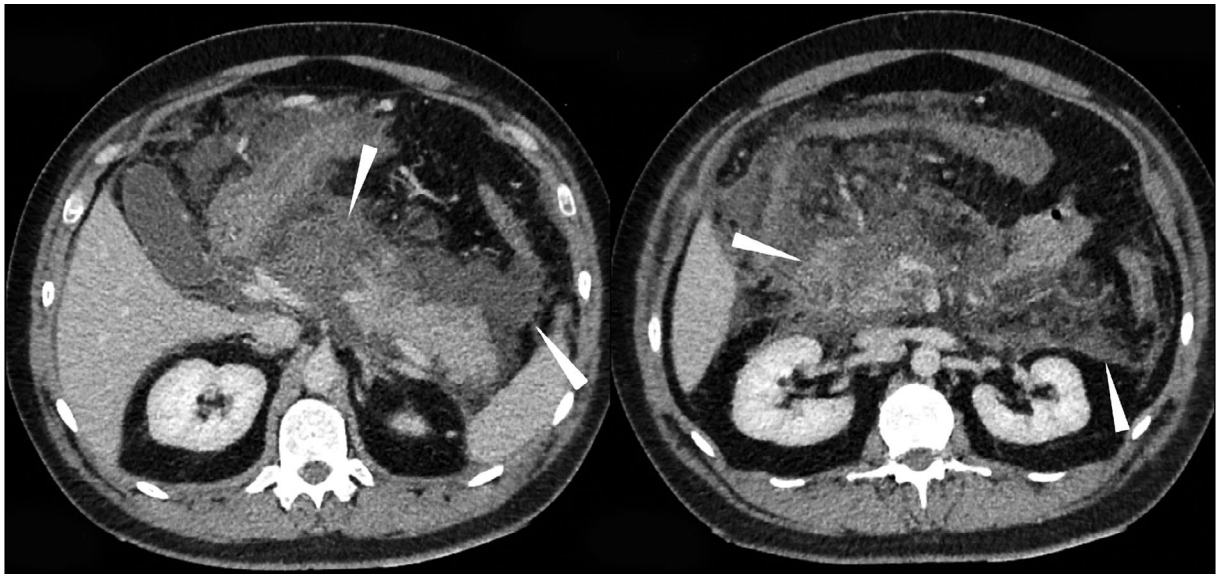

Fig. 2. Computed tomography of the abdominal organs with intravenous contrasting: infiltration and fluid accumulations in the peripancreatic fatty tissue, along the perirenal fascia on the left, in the parenchyma of the pancreatic head and body (arrows)

drainage was used to prevent erosion of the intestinal wall and infection of the retroperitoneal space.

In the postoperative period, following the occurrence of cardiovascular and respiratory failure, the patient was extubated on day 2 (February 2, 2018). The comprehensive therapy had a positive effect, with a decrease in leukocytosis to 10×10^9 g/l in the general blood test in presence of a persistently high C-reactive protein level (241 mg/l). Then, during the week, the patient had daily dressings with revision and sanitation of the omentobursostomy. During the revision of the omentobursostomy, no additional leaks or free-lying sequesters were found.

At the control AO CT scan (02/01; 02/02; 02/05/2018), the CT presentation showed no deterioration; the state of the pancreas and fluid accumulation along the gland contour in the area of the omental sac had changed; non-draining fluid accumulations in the retroperitoneal space were not detected (Fig. 3).

After the condition stabilization, on tenth day after the surgery, the patient was transferred to the surgical department. After numerous necrosequestrectomy for 9 days, flow aspiration drainage of the omental sac cavity was established.

The control TO and AO CT (February 14; February 21, 2018) revealed a decrease in the left-sided hydrothorax and resolution of the area of consolidation in the lower lobe of the left lung, as well as a decrease in effusion in the peripancreatic tissue and infiltrative changes in the fatty tissue of the abdominal cavity (Fig. 4).

Clinically, the formation of an external pancreatic fistula was noted. On February 28, 2018, the patient underwent MR cholangiography, which revealed that the Wirsung's duct at the level of the head and body of the pancreas was not visualized; that it had a tortuous course in the tail, with uneven contours and a diameter of 2 mm; and that no fistulous tracts were detected. Intra- and extrahepatic bile ducts were not dilated (Fig. 5).

Over the next month, conservative therapy and flow aspiration drainage of the omental sac were performed. The patient's condition improved to the point of being satisfactory, the fever subsided, and an external pancreatic fistula was formed. In the outpatient setting, the patient was discharged under the supervision of a surgeon.

The control AO CT on March 23, 2018, detected a decrease in the size of the infiltrate anterior to the body and tail of the pancreas, as well as a decrease in the infiltrate along the ascending colon; the gland was reduced in size, with the sagittal size of 17 mm at the level of the tail and 6 mm at the level of the body, and it was not significantly differentiated at the level of the gland head (Fig. 6).

Thus, timely diagnostics enabled the most appropriate treatment approach to be chosen in the demonstrated clinical case, which improved the prognosis of the disease, with the acute and subacute periods ending relatively well.

DISCUSSION

L. Sorrentino et al. [20] used a minimally invasive approach in the treatment of severe pancreatic necrosis, namely endoscopic transgastric necrosectomy. At the first stage, our treatment approaches are similar, namely, diagnostic laparoscopy and drainage of the abdominal cavity; however, at the second stage, we preferred to expand the surgical intervention with conversion to laparotomy and formation of an omentobursostomy to facilitate access to the omental sac for necrosequestrectomy.

A group of Japanese scientists describes successful treatment of a patient with necrotic pancreatitis using a combination of continuous drainage of the skin wound by negative pressure and endoscopic necrectomy [21]. Another

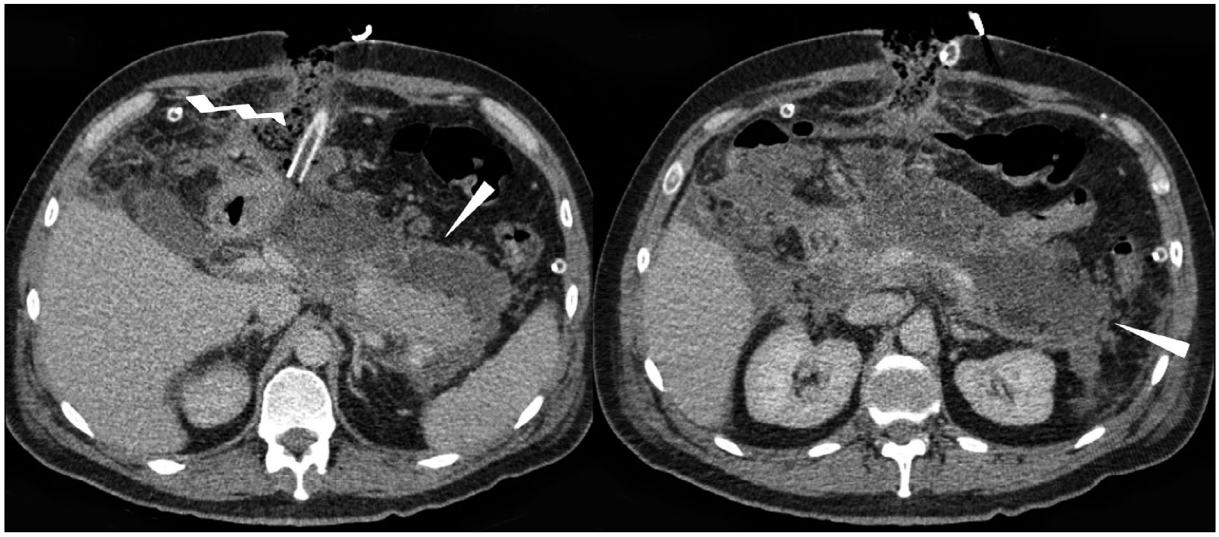

Fig. 3. Computed tomography of the abdominal organs with intravenous contrasting: infiltration and fluid accumulations in the peripancreatic fatty tissue, along the perirenal fascia on the left, in the parenchyma of the pancreatic head and body (arrows); drain tube (zigzag arrow in the image on the left). The formation of a thin contrasting capsule along the infiltration zone over time is noted

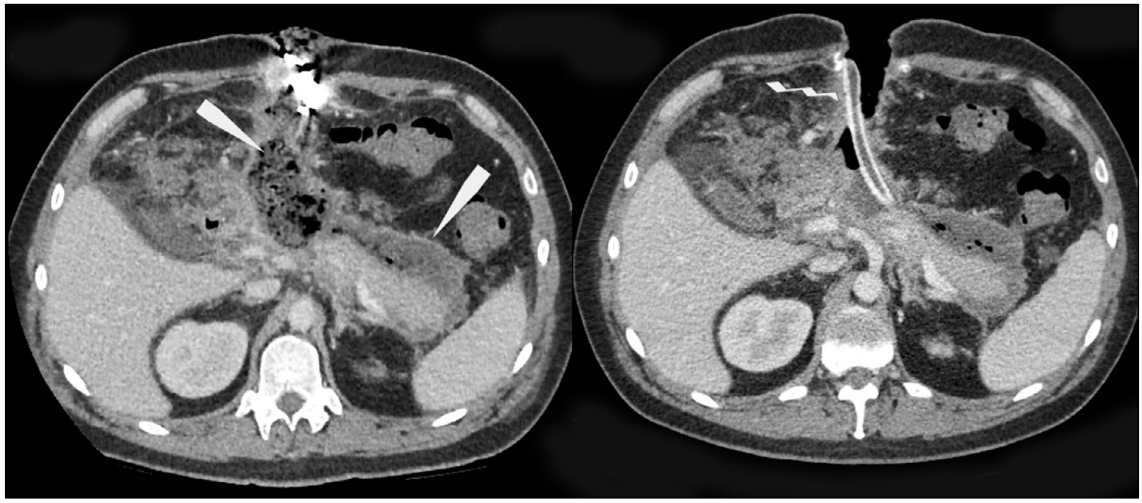

Fig. 4. Computed tomography of the abdominal organs with intravenous contrasting: encapsulated infiltration and fluid accumulation in the peripancreatic adipose tissue, which decreased over time (image on the left, arrows), a hemostatic sponge in the cavity of the encapsulated contents; drain tube (image on the right, zigzag arrow). Further formation of a thin contrasting capsule along the course of the infiltration zone over time is noted

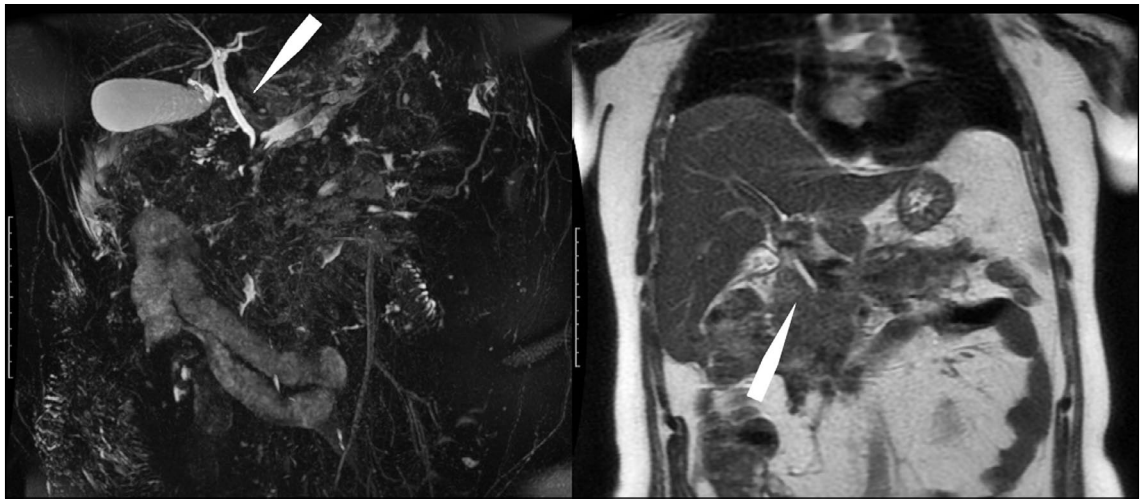

Fig. 5. Magnetic resonance imaging cholangiography (left) and T2-WI (coronal plane, right). The distal part of the common bile duct is "hidden" in the infiltrate; the proximal part of the common bile duct and the intrahepatic bile ducts are not dilated (arrows)

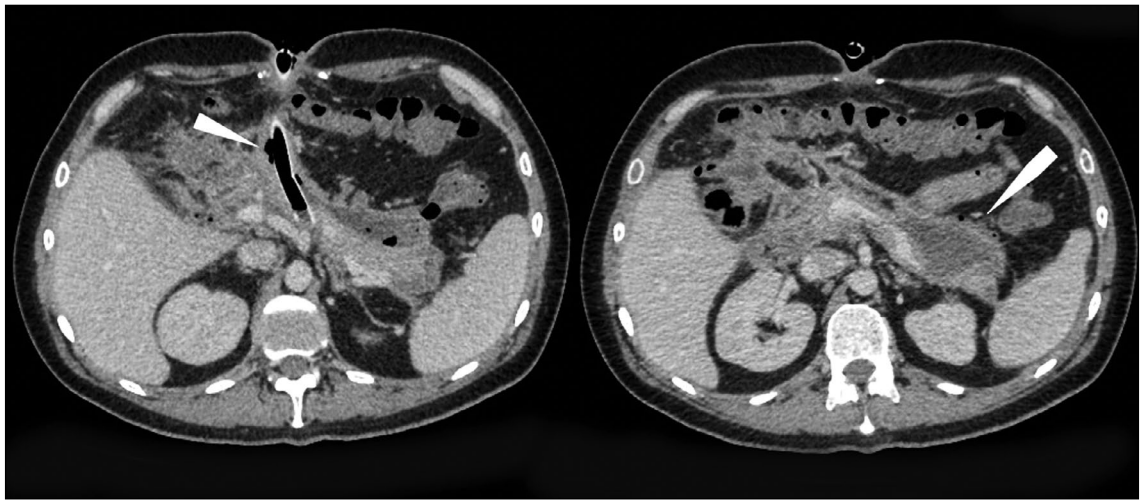

Fig. 6. Computed tomography of the abdominal organs with intravenous contrasting: drainage tube (left image, arrow); encapsulated infiltration and fluid accumulation in the peripancreatic fatty tissue, which decreased over time (image on the right, arrow)

clinical case [22] demonstrated the development of necrotic pancreatitis following an ampullary biopsy in Barrett's esophagus, with subsequent treatment involving repeated drainage of the necrotic cavity under CT guidance.

In all the clinical cases presented, including ours, in addition to clinical and laboratory data, CT with intravenous contrasting was actively used for diagnostics, assessment of the course of the disease, and choice of treatment approach.

Thus, the best time to diagnose acute pancreatitis is 72 hours to 5 days after the onset of disease symptoms. During this period, edema and transient ischemia of the pancreas can be misdiagnosed as necrosis and resolved in subsequent studies, and local complications may develop without clinical correlations. In the patient, in the case presented, during the period of a stable severe clinical presentation, the transition of phase IA to phase IB of the disease development was recorded.

Clinical guidelines recommend using CT to rule out local complications when the clinical presentation changes and/or the patient's condition deteriorate sharply. In the case presented, the patient's CT was sensitive to changes in the clinical presentation and recorded a transition at the beginning to phase IIA of aseptic sequestration, followed by phase IIB of septic sequestration with the formation of a parapancreatic abscess.

CT is a necessary study when planning minimally invasive surgical interventions, which are currently preferred in the treatment of necrotic pancreatitis. This approach was used on our patient.

In pancreatic necrosis, MRI is the method of choice for assessing the condition of the common bile duct and the Wirsung's duct, which was very important for our patient who developed an external pancreatic fistula during the treatment of necrotic pancreatitis.

CONCLUSION

To date, methods of radiation diagnostics combined with adequate therapeutic and surgical approaches can improve the prognosis of the course of necrotic pancreatitis.

ADDITIONAL INFORMATION

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Authors' contribution. S.I. Kitavina — preparation and writing of the text of the article; V.S. Petrovichev — text writing and article editing; A.N. Ermakov — literature review, collection and analysis of literary sources review of literature, edition illustrative material of the article; N.A. Ermakov — writing of the text of the article, preparation illustrative material of the article; I.G. Nikitin — article editing. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

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Поражение костей таза, позвоночника и рёбер при остеопойкилии: клинический случай

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АННОТАЦИЯ

Остеопойкилия — редкая форма наследственной доброкачественной дисплазии костей, случайно обнаруживаемая при рентгенографии. Характеризуется специфической рентгенологической картиной — диффузными склеротическими участками кости круглой или овальной симметричной формы, определяемыми по всему скелету. Правильная постановка диагноза очень важна, поскольку поражения такого типа схожи с костными метастазами.

В данной статье представлен случай остеопойкилии у пациентки, обратившейся в нашу клинику с жалобой на кратковременную потерю сознания без признаков онемения, покалывания, слабости в ногах или других частях тела. Компьютерная томография показала множественные мелкие склеротические очаги, рассеянные по грудному и поясничному отделу позвоночника, рёбрам, тазовым костям, крестцу и проксимальному отделу бедренных костей с обеих сторон. При остеосцинтиграфии всего тела с применением технеция-99м повышения накопления препарата не выявлено. У пациентки были диагностированы характерные рентгенологические признаки остеопойкилии, после чего она находилась под наблюдением.

Ключевые слова: остепойкилия; дисплазия костей; клинический случай.

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Osteopoikilosis in the ribs, pelvic region and spine: a case report

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ABSTRACT

Osteopoikilosis is a rare inherited benign bone dysplasia incidentally found on radiological exams. It is characterized by a specific radiological pattern: diffuse, round or oval, symmetrically shaped sclerotic bone areas distributed throughout the skeleton. It is essential to do a correct diagnosis because these lesions could be easily confused with bone metastasis.

We reported a case of an osteopoikilosis patient presenting to our clinic with transient loss of consciousness and without any numbness, tingling and weakness in the legs or other parts of the body. The computed tomography scan showed multiple small sclerotic foci bone islands, scattered throughout the thoracic and lumbar spine, ribs, pelvic bone, sacrum and bilateral proximal femur. No significant increase in the activity was detected in technetium-99m whole-body bone scintigraphy. The patient was diagnosed with characteristic radiological findings of osteopoikilosis and was followed up.

Keywords: osteopoikilosis; bone dysplasia; clinical case.

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肋骨、骨盆区和脊柱脆性骨硬化：一份病例报告

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摘要

脆性骨硬化是一种在放射学检查中偶然发现的罕见遗传性良性骨发育不良。其特征是具有特殊的放射学表现：分布于整个骨骼的弥漫性、圆形或椭圆形、形状对称的骨硬化区。这些病变很容易与骨转移瘤相混淆，因此做出正确诊断至关重要。

本文报告了一例脆性骨硬化患者，其因一过性意识丧失前来我们门诊就诊，双腿或身体其他部位无任何麻木、麻刺感和虚弱。计算机断层成像扫描示多发小面积硬化性骨岛，散布于胸腰椎、肋骨、骨盆、骶骨和双侧股骨近端。锝-99m全身骨显像未检测到活性显著增加。

患者被诊断为脆性骨硬化典型放射学表现，并接受随访。

关键词：脆性骨硬化；骨发育不良；临床病例。

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BACKGROUND

Osteopoikilosis is a rare benign bone dysplasia that affects about one in every 50,000 people, usually with no age or gender differences [1].

It is characterized by numerous circular or ovoid sclerotic bone lesions symmetrically distributed throughout the skeleton [2]. Lesions are frequently found incidentally on imaging studies for unrelated complaints [3]. Histologically, the lesions are thicker trabeculae of lamellar osseous tissue with haversian systems within the cancellous structure; they are most likely foci of bone that did not become cancellous throughout growth and differentiation. The condensation of cancellous bone in osteopoikilosis consists of a peripheral area of trabeculae in which osteocytes are scant, and there are no osteoblasts or osteoclasts (both are present in the central core of irregular trabeculae) [4,5].We report a case of osteopoikilosis patient who presented to our clinic for a syncope.

DESCRIPTION OF THE CASE

A 43-year-old female patient was taken to the emergency room by ambulance after experiencing transient loss of consciousness. The initial evaluation consisting of history, physical examination, 12-lead electrocardiogram and laboratory tests did not reveal any abnormalities; thus, a total-body computed tomography (CT) was performed. The CT scan showed multiple small sclerotic foci bone islands, scattered throughout the thoracic (Figure 1a) and lumbar spine (Fig. 1b), ribs, pelvic bone (Fig. 2), sacrum (Fig. 3) and bilateral proximal femur (Fig. 4). All bones were free of any cortical erosion or periosteal reaction. No other signs, such as rubor or edema, were noticed; moreover, the patient did not describe any numbness, tingling and weakness in the legs or other parts of the body.

The CT pattern was suspicious for osteopoikilosis. The relative clinical and laboratory tests, such as routine blood count, erythrocyte sedimentation rate, serum electrolytes, tumor markers, alkaline and acid phosphatase, ANA and anti-DS-DNA were negative for any type of arthritis, infection or osteoblastic bone metastases, which were in the differential diagnosis. No significant increase in the activity was detected in technetium-99m whole-body bone scintigraphy. The patient was diagnosed with typical radiological findings of osteopoikilosis by excluding other differential diagnoses and was followed up.

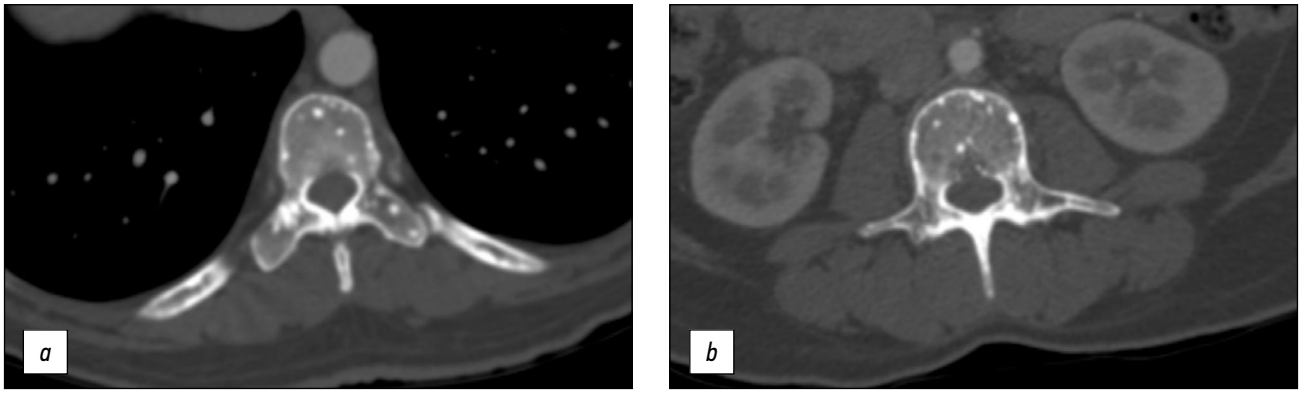

Fig. 1. Transverse cross-section computed tomography scan passing through the thoracic (*a*) and lumbar (*b*) spine. It shows numerous, well-defined, homogeneous, circular, hyperdense foci in spinous processes and vertebral arches**.**

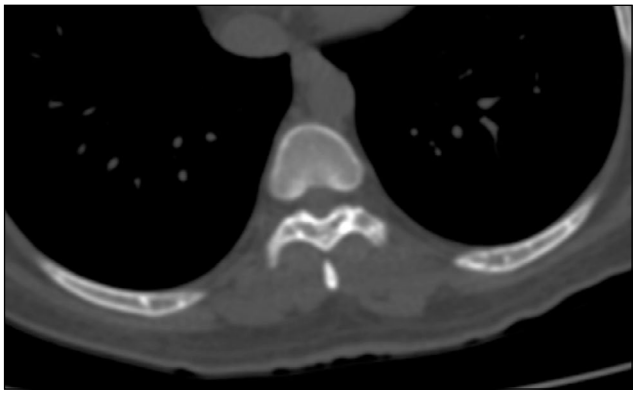

Fig. 2. Transverse cross-section computed tomography scan passing through the seventh rib. It shows numerous hyperdense lesions; these are well-circumscribed and are measured in millimeters.

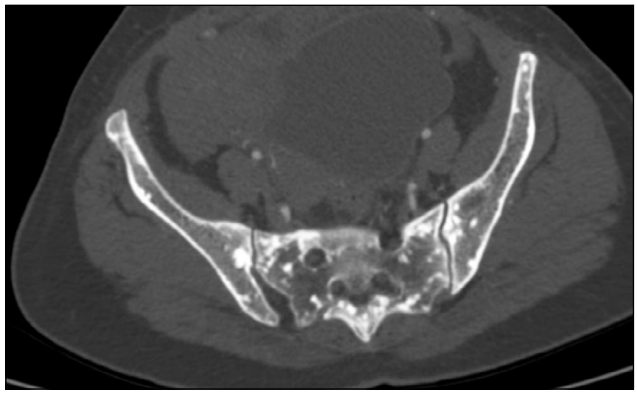

Fig. 3. Transverse cross-section computed tomography scan passing through the sacroiliac joints. It shows small, sclerotic, round opacities distributed symmetrically along sacrum, hip bone, and sacroiliac joints.

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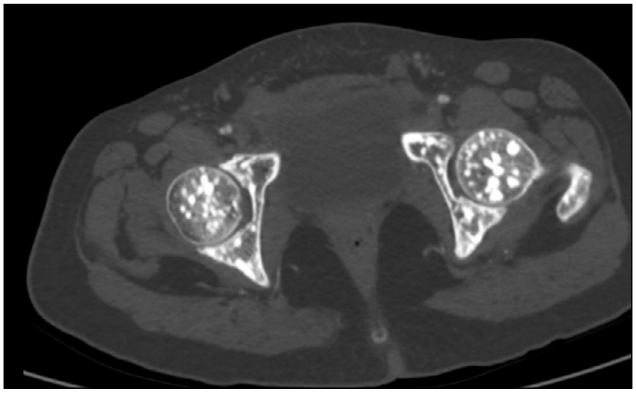

Fig. 4. Transverse cross-section computed tomography scan passing through the femoral head. It shows numerous hyperdense lesions that conform with the osteopoikilosis in the femoral head; lesions are well-circumscribed and are measured in millimeters.

DISCUSSION

Osteopoikilosis (also known as "spotted bone disease" or osteopathia condensans disseminata) is a rare bone dysplasia and was first described by Albers-Schönberg in 1915 [6]. The incidence of this disease is estimated around one in 50,000, usually without age or gender differences [1]. It is usually autosomal dominant in inheritance, but sporadic forms are also reported [1]. Current literatures suggest loss-of-function mutations of *LEM domain-containing 3* (*LEMD3*) gene located on 12q might be the cause. These mutations could also affect soft tissue and skin, causing melorheostosis that is a benign sclerosing bone dysplasia with cortical hyperostosis, thickening and fibrosis of overlying skin and Buschke–Ollendorff syndrome that comprises osteopoikilosis associated with disseminated connective tissue and cutaneous yellowish nevi [7,8]. Osteopoikilosis lesions are typically found incidentally on imaging studies done for unrelated complaints [3]. Radiological lesions of osteopoikilosis are typical: they are characterized by numerous symmetrical, homogeneous, well circumscribed, small (1–10 mm in diameter) and round or oval shaped sclerotic lesions. The most commonly affected areas are the epiphyses of short tubular bones and the metaphyses of long bones. In addition, carpal and tarsal bones, scapula, pelvis and sacrum are reported to be frequently affected [9,10]. Ribs, clavicles, spine and skull involvement is uncommon [11]. Because of their similarities, the radiological lesions of osteopoikilosis can be confused with osteoblastic bone metastases, but there are significant differences that allow us to make a differential diagnosis. In contrast to bone metastasis, the sclerotic lesions in osteopoikilosis are symmetrical, consistent in size and do not induce cortical erosion. As a result, bone scintigraphy plays an important role in definitive diagnosis; in fact, a normal radionuclide bone scan generally excludes the possibility of osteoblastic bone metastasis. Nevertheless, several cases of osteopoikilosis with an abnormal bone scan have been reported in the literature [12,13].

CONCLUSION

Although osteopoikilosis is a rare condition, it can be easily diagnosed through its typical radiological findings. Therefore, clinicians must be aware of and recognize this image pattern in order to make an accurate diagnosis and prevent further examinations and aggressive treatments.

ADDITIONAL INFORMATION

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Authors' contribution. M.T. Paparella, I. Gangai — contributed equally to the research work related to the topic and the manuscript writing; C. Porro, L. Eusebi, F. Silveri — literature research and data acquisition; A. Cammarota, G. Guglielmi — critical revision of manuscript. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Consent for publication. Written consent was obtained from the patient for publication of relevant medical information and all of accompanying images within the manuscript.

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Возрастающая роль функциональной визуализации для навигации радиотерапии и брахитерапии на примере рака предстательной железы

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АННОТАЦИЯ

Брахитерапия успешно применяется в лечении злокачественных новообразований у мужчин и женщин, в редких случаях у детей, как самостоятельный метод (например, при локализованном раке предстательной железы) или адъювантный с дистанционной фокальной лучевой терапией (например, при раке шейки матки, анального канала, головы и шеи, молочной железы и пр.).

Расширение диагностических возможностей (появление компьютерной и магнитно-резонансной томографии) благодаря трёхмерной визуализации дало брахитерапии важное технологическое преимущество перед другими методами. Существует множество вариантов сочетания брахитерапии с дистанционной лучевой или системной противоопухолевой терапией в первой линии, а также в монорежиме при локализованном рецидиве опухоли в ранее облучённой зоне.

Введение интрастатов (полых трубок) для внутритканевой высокодозной брахитерапии осуществляется во время операции, а инкапсулированных (закрытых) радиоактивных микроисточников для низкодозовой брахитерапии — напрямую (чрезкожно).

Отличительной спецификой брахитерапии является резкое падение дозы за пределами опухолевого очага, что минимизирует риск облучения окружающих органов и тканей.

Основным преимуществом брахитерапии в сравнении с дистанционной лучевой терапией является более высокий градиент дозы облучения на границе опухоли (со всех сторон). Более того, нет необходимости уточнения границ неопределённости при облучении мишени: когда опухоль изменяется в процессе лечения, то фиксированные в опухоли источники синхронно меняют своё положение.

Помимо преимуществ в эффективности и безопасности, совокупные финансовые затраты при брахитерапии существенно ниже других вариантов лучевой терапии.

Ключевые слова: молекулярная визуализация, брахитерапия; радиотерапия, рак предстательной железы.

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The increasing role of functional visualization modalities for navigation of external beam radiation therapy and brachytherapy in prostate cancer

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ABSTRACT

Brachytherapy is successfully used in the treatment of malignant neoplasms in males and females and rare cases in children, as an independent method (with localized prostate cancer) or adjuvant with remote focal radiation therapy (with cancer of the cervix, anal canal, head and neck, breast, etc.).

The expansion of diagnostic capabilities (the advent of computer and magnetic resonance imaging) due to three-dimensional imaging has given brachytherapy an important technological advantage over other methods. Many options are available for combining brachytherapy with remote radiation or systemic antitumor therapy in the first line, as well as in a single mode for localized tumor recurrence in a previously irradiated area.

Intrastates (hollow tubes) for intra-tissue high-dose brachytherapy are administered during surgery and encapsulated (closed) radioactive micro-sources for low-dose brachytherapy are directly administered (percutaneously).

A distinctive feature of brachytherapy is a sharp drop in the dose outside the tumor focus, which minimizes the risk of irradiation of surrounding organs and tissues.

The main advantage of brachytherapy in comparison with remote radiotherapy is a higher radiation dose gradient at the tumor border (from all sides). Moreover, clarifying the boundaries of uncertainty when irradiating the target is unnecessary. When the tumor changes during treatment, the sources fixed in the tumor synchronously change their position.

In addition to the advantages in efficiency and safety, the total financial costs of brachytherapy are significantly lower than other radiotherapy options.

Keywords: brachytherapy; prostate cancer; malignant neoplasms; radiation therapy.

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在前列腺癌病例中，功能成像方法在导航远程放射治疗和近距离放射治疗中的作用越来越大

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简评

近距离放射治疗已成功用于治疗男性和女性的恶性肿瘤，很少用于儿童，无论是单独治疗（如局限性前列腺癌）还是辅助外照射治疗（如宫颈癌、肛管癌、头颈癌、乳腺癌等）。

三维成像带来的诊断能力的扩展（计算机断层扫描和磁共振成像的出现）使近距离放射治疗比其他方法具有重要的技术优势。在第一线，近距离放射治疗与外照射或全身抗癌治疗相结合有许多选择，对于先前照射区域的局部肿瘤复发，也有单一疗法。

在手术期间引入用于间质高剂量近距离放射治疗的intrastats（空心管），并直接（经皮）封装（封闭）用于低剂量近距离放射治疗的放射性微源。

近距离放射治疗的一个显著特点是肿瘤病灶外的剂量急剧下降，从而将周围器官和组织的辐射风险降至最低。

与外束放射治疗相比，近距离放射治疗的主要优点是在肿瘤边缘（从四面八方）有更高的辐射剂量梯度。此外，无需澄清靶向照射过程中的不确定性限制：当肿瘤在治疗过程中发生变化时，固定在肿瘤中的放射源同步改变其位置。

除了疗效和安全效益外，近距离放射治疗的总财务成本大大低于其他放射治疗方案。

关键词：近距离放射治疗；前列腺癌；恶性肿瘤；放射治疗。

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INTRODUCTION

Historically, dosimetric planning for prostate cancer brachytherapy was based on 2D orthogonal computed tomography (CT) pelvic views obtained during implantation. Although radiographic images allowed for accurate visualization of the applicators, they did not provide an accurate estimate of the volume of the target lesion or healthy tissues/organs near the tumor, which could be damaged by irradiation (organs at risk). In the 1990s, with the advancement of diagnostic capabilities, namely, the advent of CT and magnetic resonance imaging (MRI), brachytherapy benefited greatly due to the technological advantages of three-dimensional imaging, so the question of further improving the accuracy of brachytherapy under MRI navigation naturally arises. Moreover, in addition to the efficiency and safety benefits, brachytherapy has significantly lower total financial costs than other radiotherapy options [1].

COMBINED FUNCTIONAL AND ANATOMICAL IMAGING METHODS

The use of brachytherapy in conjunction with external beam radiation or systemic antitumor therapy is becoming increasingly popular in oncology, adding a new dimension to patient management. The functional visualization of organs during physiological processes is complementary to the anatomical image, which contains complete information about the structure of the organs.

At present, many complementary biological processes, such as metabolic activity, cell proliferation, perfusion, hypoxia, etc. can be visualized. Diagnostic functional images in oncology are used to assess the distribution of tumor cells and detect intratumoral heterogeneity, as well as to establish phenotypic characteristics and the nature of the microenvironment in solid tumors, which affect the clinical course and therapeutic response. The largest number of studies has been conducted to determine the mass of the tumor and its clonogenic density, hypoxia, or proliferation.

The combination of functional and anatomical imaging provides structural and metabolic information about the tumor, allowing different subtypes and radioresistant zones in tumor foci to be identified.

Magnetic resonance imaging

Due to the high resolution and high contrast of soft tissues, MRI has become the standard method of anatomical imaging for determining the stage and prevalence of primary tumors. MRI offers numerous technological options for detecting the mechanisms of functional organization of a tumor, such as angiogenesis (perfusion MRI), metabolism (MR spectrometry), and even its cellular composition (diffusion-weighted imaging, DWI). In MRI, the dynamic contrast enhancement (DCE) mode is a technique for flexible analysis of changes in tissue signal intensity following injection of a standard paramagnetic contrast agent (based on gadolinium). The difference in tissue perfusion after injection of a gadolinium-based contrast agent can be evaluated using MRI in DCE mode. Using at least two different b-values in DWI mode, the apparent diffusion coefficient (ADC) can be calculated during postprocessing. Most malignant tumors have increased cell density, which is displayed as increased signal intensity on DWI or a decrease in ADC in quantitative analysis.

Positron emission tomography

Positron emission tomography combined with CT (PET/CT) or MRI (PET/MRI) has significantly improved the diagnostics and staging of malignant neoplasms (lungs, prostate, hematopoietic system, etc.). Despite having a lower spatial resolution than modern CT and MRI, PET allows for the detection of metastases that other methods do not reveal and allows for the initial optimization of the treatment approach. In addition, PET can provide unique functional information about a tumor, such as zones of hypoxia, proliferation, radioresistance, etc. At the current stage, a wide range of "metabolic" radiotracers (radiopharmaceuticals) are available in nuclear medicine (Table 1).

Digital biomarkers: radiomics

Clinical aspects and anatomical imaging techniques provide important prognostic information regarding the clinical course of a tumor, but they cannot predict the response of a tumor to treatment. The development of reliable prognostic biomarkers could improve the choice of the optimal treatment approach and individualize the therapeutic approach. Radiomics, as a method of extracting and analyzing large amounts of quantitative radiological data from medical images using high-performance methods, can be used to develop digital biomarkers that can be used in choosing the most effective and safe treatment approach. Digital biomarkers perfectly complement the qualitative and quantitative characteristics of the tumor process, such as clinical manifestations, morphological pattern, and metabolomic (in particular, tumor markers) and molecular genetic studies. Comprehensive consideration of all significant parameters enables the development of reliable predictive models that improve patient treatment outcomes and the development of medical decision support systems based on evidence-based clinical experience and creative international multidisciplinary communication.

RELIABLE PROGNOSTIC MODELS AS A DECISION SUPPORT SYSTEM

Brachytherapy allows for the delivery of heterogeneous doses within the volume of the irradiated target; however, there is a risk of local recurrence, which is associated with radioresistance of the remaining tumor foci in particular. Functional imaging provides a presentation of tumor biology, allowing for more adaptable dosage distribution to the actual

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Table 1. Range of radiotracers for molecular imaging in oncology and endocrinology

Metabolic pathway	Scope of application	Molecular imaging method	
		SPECT/CT	PET/CT
Energy glycolysis	Oncology	-	^{18}F-FDG
Synthesis of thyroid hormones	Endocrinology, oncology (thyroid diseases)	$^{99m}TcO_4$ (pertechnetate) ^{123}I ^{131}I	^{124}I
Hypoxia	Oncology	-	^{18}F-FAZA (nitroimidazole) ^{18}F-FISO ^{64}Cu-ATSM
Proliferation	Oncology	-	^{18}F-FLT
Cell membrane	Oncology	-	^{18}F/^{11}C-choline
Somatostatin receptors (STR 2.5)	Endocrinology, oncology (neuroendocrine tumors)	^{99m}Tc-HYNIC-TOC (tectrotide)	^{68}Ga/^{64}Cu-DOTA-TATE/NOC/TOC
Norepinephrine synthesis	Endocrinology, oncology (pheochromocytoma, paraganglioma, neuroblastoma)	^{123}I/^{131}I-MIBG	^{124}I-MIBG
Glucagon-like peptide type 1 receptors (GLP-1)	Endocrinology, oncology (insulinoma)	^{99m}Tc-HYNIC-exendin-4 (tectrotide)	^{68}Ga/^{64}Cu-DOTA-exendin-4
Estrogen receptors	Endocrinology, oncology	-	^{18}F-FES
Androgen receptors	Endocrinology, oncology	-	^{18}F-FDHT
her2neu receptors	Oncology	-	^{89}Zr-DFO-trastuzumab
PSMA receptors	Oncology	^{99m}Tc-HYNIC-PSMA	^{68}Ga/^{18}F-PSMA
Activity of tumor-associated fibroblasts	Endocrinology, oncology	-	^{68}Ga/^{18}F-FAPI
Bone metabolism	Endocrinology, oncology	^{99m}Tc-MDP (technefor, pyrfotech etc.)	^{18}F-NaF (Sodium fluoride)

Note. FDG, fluorodeoxyglucose; FAZA, fluoroazomycin arabinoside; ATSM, diacetyl-bis-N4-methylthiosemicarbazone; MIBG, metaiodobenzylguanidine; FES, fluoroestradiol; FDHT, fluorodihydrotestosterone; PSMA, prostate-specific membrane antigen

tumor site. The planned total focal dose of radiation either can be individualized, with dose levels set for the full volume of the target, or can have different sublevels of radiation doses, such as the dominant tumor focus or, for example, more radioresistant hypoxic foci (biological target volume).

The potential role of functional imaging in radiation oncology is important at all stages of the management of patients with prostate cancer, namely, at stage 1 for primary tumor staging; stage 2 for planning radiotherapy in order to determine more accurately the target volumes or escalate the radiation dose; and stage 3 for case follow-up of patients in order to control the achievement of a complete response as well as detection of tumor recurrence.

For cancers of the prostate, surgical treatment, external beam radiation therapy, and brachytherapy are the preferred treatment options. The American Society of Clinical Oncology recently validated the role of brachytherapy. For low-risk carcinomas not suitable for active follow-up, brachytherapy with microsources of iodine-125 remains the treatment method that provides the best balance of biochemical control with optimal preservation of sexual function [2]. Brachytherapy should be offered as a supplementary treatment option to patients who have an unfavorable (moderate or high) risk of biochemical recurrence. Thus, based on the results of three randomized clinical trials involving a combination of external beam radiation therapy and brachytherapy, it was concluded that additional brachytherapy significantly improved survival without signs of biochemical recurrence [3]. When compared to treatment outcomes after only external beam radiation therapy or radical prostatectomy (propensity-scored pairwise test) for prostate cancer with a very high risk of biochemical recurrence (Gleason 9–10), the addition of brachytherapy improved not only survival without biochemical recurrence and without metastases but also overall 7-year survival rate [4].

Multiparametric MRI (mpMRI) and PET/CT have emerged as promising modalities for staging primary and recurrent prostate cancer. New PET/CT tracers have improved the detection of small, early-stage metastatic tumors. Moreover, cross-validation is required to determine the nature and clinical significance of these latent and PET/CT-detectable lesions. Based on the clinical status of the patient at the time of the visit, the following strategies can be suggested [5]:

- Suspected localized prostate cancer: mpMRI
- Suspected advanced prostate cancer: PET/CT with ^{68}Ga-PSMA-11, osteoscintigraphy
- Biochemical recurrence after treatment: PET/CT with ^{68}Ga-PSMA-11, as well as mpMRI for local control or MRI to evaluate lymph nodes and bone structures

Despite its high prognostic value, the Gleason score often underestimates the additional contribution of radiomics in clarifying the true clinical stage at the time of biopsy [6].

In real clinical practice, a previously unknown metastatic lesion of regional lymph nodes or distant metastases can be detected. PET/CT-detected lesions with high expression of prostate-specific membrane antigen (PSMA) receptors have a high risk of tumor aggressiveness [7]. In particular, these data help to improve understanding of the prognosis of aggressiveness and the risk of tumor recurrence, as well as the optimal selection of patients for brachytherapy and other treatment options.

Planning of brachytherapy for prostate cancer involves the entire volume of the prostate as a target for irradiation. The radiation dose of the gland is heterogeneous, and an ablative dose of radiation must be applied to all intraglandular tumor foci. According to recent findings, combining mpMRI and ^{68}Ga-PSMA PET/CT improves diagnostic accuracy in identifying these intraglandular tumors. PET/MRI with ^{68}Ga-PSMA outperforms mpMRI in accuracy (area under ROC curve 0.88 vs. 0.73; $p < 0.001$) and PET/CT (0.88 vs. 0.83; $p = 0.002$) for localized prostate cancer. PET/CT with ^{68}Ga-PSMA was more accurate than mpMRI (0.83 vs. 0.73; $p = 0.003$) [8]. Similar results were obtained by P. Donato et al. [9], as PET/CT with ^{68}Ga-PSMA detected tumor foci more frequently (78%; ROC 0.817) than mpMRI (69%; ROC 0.729).

Recently, there has been an increased interest in methods of focal therapy for prostate cancer, in patients with tumors of low (in an independent version) and high (in addition to other methods of focal therapy) risk. There is mounting evidence that dominant carcinoma foci within the prostate gland have the highest predictive value for the development of metastases and tumor recurrence after primary therapy. This highlights the need for improved visualization of carcinoma foci in terms of their dominance in size and prediction of biological aggressiveness. S. Rylander et al. [10] published the results of a dosimetric study of three mpMRI-guided low-dose brachytherapy models: (1) a "risk-adaptive" plan with prostate radiation dose de-escalation of at least 125 Gy (clinical target volume, CTV), (2) plan determined by mpMRI with dose escalation to 145–250 Gy (gross tumor volume, GTV) and a 5-mm exposure limit for all tumor foci, and (3) reference plan with a standard clinical prostate radiation dose of 145 Gy. With a significant dose reduction to the urethra and bladder neck, the risk-adaptive planning concept and dose escalation model for macroscopically defined tumor foci were technically feasible [10]. Recent studies have examined the effect of a local boost of high-dose brachytherapy on dominant intraprostatic lesions using mpMRI- or PET/CT-guided functional imaging. These two studies demonstrated excellent tolerability and low toxicity of treatment, as well as considerable structural and biochemical response rates. C.C. Hsu et al. [11] reported the results of low-dose brachytherapy with mpMRI-guided planning in patients who had previously received low-dose brachytherapy. This technology is quite feasible in clinical practice alongside others (surgery, external beam radiation therapy) and has a much lower toxicity [11].

There are drawbacks to all imaging methods, such as the effect of artifacts during PET/CT data reconstruction on the correction of attenuation caused by the contrast agent, metal implants, and patient movement. The PET/CT presentation should be reconstructed with or without attenuation correction, as attenuation artifacts can be revealed [12]. A nuclear medicine specialist should always include information about the possible impact of artifacts discovered during the study in the conclusion. With the advancement of PET/CT and MRI resolution, it will be possible to visualize even microscopic tumor foci.

When performing brachytherapy, image registration still has a lot of uncertainty, which can lead to misunderstandings in target localization. Image registration accuracy can be improved by positioning the patient during radiation therapy on MRI and PET/CT. Simulations on MRI and PET/CT require close interaction between radiotherapists and radiologists, which is even more important in brachytherapy since the risk of anatomical deformity increases during the procedure. In order to minimize the consequences, several solutions have been proposed and studied, including the method of elastic repositioning of sources [13] and the use of MRI in the operating room where brachytherapy is performed [14]. The algorithms developed for automatic superposition of various visualizations will become more accurate overtime, increasing the rate of registration and verification.

In cases when brachytherapy is performed after external beam radiation therapy for targeted dose escalation, it is necessary to determine which imaging methods (before or after external beam radiation therapy) provided more reliable information about radioresistant lesions [15].

Functional imaging may be used as an adjunct to CT planning prior to the initiation of external beam radiotherapy, or prior to brachytherapy to adapt to an early response. Pre-therapeutic ^{18}F-FDG PET/CT aids in the identification of lesions with high aggressiveness or radioresistance (markers of hypoxia), as well as the presence of a residual tumor, which may be useful in planning the boosting of such lesions and reducing unwanted radiation exposure to risk organs.

The choice of a functional imaging method to determine the biological aggressiveness of a carcinoma is critical, and at this stage, PET/CT with various tracers-indicators of the biological properties of a tumor (^{18}F-FDG, ^{18}F-FMISO/FAZA, ^{18}F-FLT, ^{68}Ga/^{18}F-PSMA-receptor) is possible. The results of retrospective studies facilitate in the selection of a method for functional imaging of the biological characteristics of tumors, as well as in determining the dose escalation regimen or dose planning strategy. Several studies have found associations between functional imaging and (1) histological findings/(2) localized foci of residual tumor or recurrence. H. Park et al. [16] revealed a good correlation between ^{11}C-choline PET/CT and histological findings in

prostate cancer. T.F. Fassbender et al. [17] emphasized the added value of PET/CT with ^{68}Ga-PSMA-11 and ^{68}Ga-RM2, as well as their strong correlation with histological presentation. Some studies have found that areas of high tracer uptake on pre-therapeutic ^{18}F-FDG PET/CT, labeled as "hotspots," later turned out to be predominant foci of local recurrence [18, 19].

Numerous techniques for segmenting ^{18}F-FDG-positive lesions on PET/CT have been proposed in the literature. There is currently no consensus on more accurate and reliable methods. Given the low (40%) sensitivity threshold of PET/CT, the method should be used with extreme caution in the presence of small tumors that accumulate poorly in contrast, as well as in the presence of heterogeneous tracer capture within the lesion [20].

Nowadays, when planning radiotherapy, molecular imaging methods are most commonly used as auxiliary methods; however, with the expansion of the list of oncometabolic radiopharmaceuticals (tracers), the increase in the resolution of single-photon emission CT and PET, the replenishment of evidence-based experience, and the development of artificial intelligence in radiomics, the improvement of functional imaging methods for navigating radiotherapy (remote radiation therapy and brachytherapy) is expected.

Many medical centers now have ultrasound machines and CT scanners, but MRI and PET/CT are only available at a few select institutions, making it difficult for a patient to undergo a PET/MRI examination [21].

It is also necessary to consider the heterogeneity of the quality of performance and interpretation of the results of functional imaging methods, as well as their cost and study duration. Based on global evidence-based experience, it is critical to improve the indications, namely, the patient and the time it is reasonable to prescribe one or more methods of functional imaging.

CONCLUSION

Thus, functional imaging techniques hold great promise for personal optimization of radiotherapy, especially brachytherapy, in all stages of prostate cancer. The use of cutting-edge technologies and interdisciplinary integration allow us to precisely increase the efficiency and reduce the toxicity of focal therapy in each individual case.

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