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Information technologies for supporting prevention, diagnosis and management of surgical site infections in trauma and orthopedic patients

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ABSTRACT

BACKGROUND: Surgical site infections (SSIs) are one of the most common preventable healthcare-associated infections, with a significant socioeconomic burden. Information technology, particularly clinical decision support systems, has been shown to improve patient safety. However, there have been few publications on the use of these systems for the prevention and treatment of SSIs.

AIM: To develop a multifunctional patient safety information system (PSIS) for the prevention, diagnosis, and treatment of SSIs in traumatic and orthopedic surgery.

MATERIALS AND METHODS: A PSIS for traumatic and orthopedic surgeons was developed and implemented in the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics in late 2023 to early 2024. The PSIS includes two user systems: 1) an analytical and authoring system (PSIS-Manager) for subject matter experts who develop scenarios; 2) a medical system for patient data entry and access to guidelines.

RESULTS: A PSIS prevention scenario was developed based on the guidelines of the National Association of Infectious and Non-Infectious Disease Control Professionals. It includes 11 recommendations for the preoperative stage, 30 for the perioperative and intraoperative stages, 33 for SSI prevention during surgery, and 7 for the postoperative stage. A surgical antibiotic prophylaxis scenario includes 24 recommendations. Decision-making algorithms for the treatment of SSIs are based on the guidelines of the American Academy of Orthopaedic Surgeons (AAOS). Decision-making involves 6 factors providing 264 various clinical scenarios, with 9 decision options.

CONCLUSION: Scenario-based protocols can be used to support decision-making on patient management strategy, as well to control compliance with SSI prevention and treatment guidelines. Further perspectives on PSIS development in terms of SSI diagnosis and treatment include the use of artificial intelligence technologies to aid in the diagnosis of wound infections and the selection of treatment options.

Keywords: surgical site infections; clinical decision support systems; patient safety; computerized clinical guidelines.

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Использование информационных технологий для поддержки процессов профилактики, диагностики и лечения инфекций области хирургического вмешательства у пациентов травматолого-ортопедического профиля

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АННОТАЦИЯ

Обоснование. Инфекции области хирургического вмешательства (ИОХВ) являются одними из самых распространённых предотвратимых инфекций, связанных с оказанием медицинской помощи, и представляют собой значительное социально-экономическое бремя. Доказана эффективность цифровых технологий, в частности систем поддержки принятия врачебных решений, в повышении безопасности пациентов, однако публикаций о внедрении этих систем для профилактики и лечения ИОХВ немного.

Цель. Разработка многофункциональной информационной системы по безопасности пациентов (ИСБП) травматолого-ортопедического профиля в части профилактики, диагностики и лечения ИОХВ.

Материалы и методы. ИСБП для травматологов и ортопедов была разработана и внедрена в ФГБУ НМИЦ травматологии и ортопедии им. Н.Н. Приорова в конце 2023 — начале 2024 г. ИСБП включает две пользовательские системы: 1) аналитико-авторскую (ИСБП-Менеджер), предназначенную для экспертов предметной области, формирующих сценарии; 2) врачебную, предназначенную для ввода данных о пациентах и просмотра рекомендаций.

Результаты. Сценарий профилактики ИСБП разработан на основании методических рекомендаций НАСКИ, в нём предусмотрено 11 рекомендаций для предоперационного этапа, 30 — для пери- и интраоперационного этапа, 33 рекомендации по профилактике ИОХВ в операционной и 7 — для послеоперационного периода. Сценарий хирургической антибиотикопрофилактики содержит 24 рекомендации. В основе алгоритмов принятия решений о лечении ИОХВ лежат рекомендации Американской ассоциации ортопедических хирургов AAOS. В принятии решения участвуют 6 факторов, дающих 264 различные клинические ситуации, для которых предусмотрено 9 вариантов решений.

Заключение. Формируемые в результате заполнения сценариев протоколы могут не только служить для поддержки принятия решения о тактике ведения пациента, но и выступать в качестве инструмента для контроля соблюдения рекомендаций по профилактике и лечению ИОХВ. Дальнейшие перспективы развития ИСБП в части диагностики и лечения ИОХВ связаны с использованием технологий искусственного интеллекта для поддержки процессов диагностики раневой инфекции и выработки тактики её лечения.

Ключевые слова: инфекции области хирургического вмешательства; системы поддержки принятия врачебных решений; безопасность пациентов; компьютеризированные клинические рекомендации.

Как цитировать:
Назаренко А.Г., Клеймёнова Е.Б., Дронов М.А., Горбатюк Д.С., Какабадзе Н.М., Цискарашвили А.В., Герасимова Н.П., Юрченкова Е.С., Яшина Л.П. Использование информационных технологий для поддержки процессов профилактики, диагностики и лечения инфекций области хирургического вмешательства у пациентов травматолого-ортопедического профиля // Вестник травматологии и ортопедии им. Н.Н. Приорова. 2024. Т. 31, № 4. С. 467–479. DOI: https://doi.org/10.17816/vto636446

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BACKGROUND

Surgical site infections (SSIs) are one of the most common preventable healthcare-associated infections (HAIs) [1]. According to international studies, more than 300 million surgical procedures were performed worldwide in the first decade of the 21st century [2]. A meta-analysis of 43 publications from 39 countries found that the incidence of SSIs was 2.5% [3]. SSIs pose a significant socioeconomic burden and rank third among the most "costly" infections. In the United States, the average cost of diagnosis and treatment per case is $12–14 thousand [4]. Prolonged hospital stays, intensive care unit admissions, revision surgeries and rehospitalizations, diagnostic procedures, and antibiotic therapy incur additional costs. In the United States alone, the annual additional expenses associated with SSIs equal to $10 billion, with over 400 thousand additional days of hospital stay [5]. The social burden is associated with decreased quality of life, prolonged temporary incapacity, disability, and fatal outcomes [6]. According to official figures, 10,173 surgeries were performed in Russia in 2023. Published data on the incidence of SSIs suggest that over 254 thousand patients could have postoperative infectious complications.

In traumatic and orthopedic surgery, SSIs account for approximately 14% of in-hospital complications, with 77–95% considered preventable [7, 8]. According to recent meta-analyses, the incidence of SSIs in various traumatic and orthopedic interventions is 3.1% for spine surgery (27 studies, 22,475 patients [9]), 3.3% for long bone surgeries (12 studies, 71,854 patients [10]), 4.2% for foot and ankle surgeries (9 studies, 10,447 patients [11]), 3.0% for knee surgeries (7 studies, 11,028 patients [12]), 2.6% for primary hip and knee replacement (14 studies, 167,283 patients [13]), 10.1% for upper limb injuries (27 randomized studies, 3,867 patients [14]), and 1.1% for elective upper limb surgeries (10 studies, 817,309 patients [15]).

Notably, the majority of SSIs (60%) occur after discharge [16]. Orthopedic interventions typically have the longest time to SSI (33.5 days after surgery on average), due to the risk of delayed implant-associated infection [17]. Thus, data on the incidence of SSIs in orthopedic patients followed up for 3–12 months can differ significantly (by up to 7.6%) from the values reported above [18].

In implant-associated infections (IAIs), infection at the implant site can promote SSIs in more superficial tissues. These SSIs cannot be successfully treated unless the IAI is eliminated. The treatment requires the collaboration of an orthopedic surgeon, intensivist, plastic surgeon, vascular surgeon, infectious disease specialist, general practitioner, clinical microbiologist, and clinical pharmacologist. The treatment involves surgery and long-term antimicrobial therapy. Surgical treatment options depend on the duration of infection and patient's overall health status; they can include debridement with preserved implant, two- or one-stage implant removal and replacement, excision arthroplasty, joint fusion, and/or amputation/exarticulation.

The clinical success and cost-effectiveness of IAI treatment depend on timely diagnosis, optimal treatment strategy, and a multidisciplinary approach. For example, debridement with preserved implant and subsequent antibiotic therapy is cheaper than one- or two-stage revision surgery and less detrimental to quality of life. However, this strategy is associated with a higher risk of recurrent infection. If the patient requires surgery in the future, the overall treatment cost will be higher. Cost-effectiveness models of IAI treatment show that the recurrence rate has the greatest impact on the overall treatment cost [19].

Revision arthroplasty in IAIs is associated with an increase in:

- duration of surgery and blood loss;
- postoperative complications and in-hospital mortality;
- length of hospital stay;
- overall number of surgeries;
- hospital costs per case;
- readmission rates and return outpatient visits;
- disability and mortality [20].

This significantly increases the burden on healthcare systems, including financial burden. For example, in the UK, revision knee arthroplasty is three times more expensive in IAIs than in aseptic cases, and the third revision due to IAIs is nearly three times costlier than the first [21].

The majority of SSIs are preventable; therefore, clinicians and researchers pay significant attention to the prevention of these complications. Risk factors for SSIs are typically classified as patient-associated (modifiable and non-modifiable) and intervention-associated (surgical technique, duration of surgery, use of implants, compliance with infection control requirements, normothermia, glycemic control, and oxygenation) [22].

International guidelines typically combine the list of mandatory preventive measures with proven efficacy into the so-called care bundle [23]. The care bundle concept was introduced by the Institute For Healthcare Improvement (IHI) in 2001. It is a set of preventive measures that, when combined, provide better clinical outcomes than when used independently. For example, the Thai guidelines for the prevention of SSIs include 10 such recommendations (mainly Grade 1A). These include smoking cessation prior to surgery, body weight-adjusted antimicrobial prophylaxis with appropriate timing and repeated dose, adequate hair removal, skin preparation with an alcohol solution, wound protectors in abdominal surgeries, antimicrobial-coated sutures (for abdominal wall closure), perioperative glycemic control, intraoperative normothermia, perioperative oxygen saturation ≥92%, and changing of contaminated gloves and surgical tools prior to wound closure [24]. Compliance with the care bundle significantly reduced the incidence of SSIs in colorectal surgeries (by 61%) [25].

A systematic review on the use of care bundle for the prevention of SSIs in arthroplasty [26] revealed 11 studies. The number of mandatory requirements ranged from 3 to 22, the compliance rate was 77.3% to 94.7%, and the incidence of SSIs decreased by 24% (according to 4 studies).

In Russia, the National Association of Healthcare-Associated Infection Control Professionals regularly updates the guidelines for the prevention of HAIs [27]. The requirements of these guidelines are similar to those of the care bundle; however, they are not always considered in the guidelines proposed by other medical communities.

Digital technologies, particularly clinical decision support systems (CDSSs), are a well-accepted way for increasing compliance with guidelines by providing clinicians with “the right information at the right time and in the right form.” CDSSs are known to have a positive impact on compliance with guidelines in various fields of medicine, including improved clinical workflows, better treatment outcomes, and lower complication rates [28, 29]. Despite the proven efficacy of CDSSs, their widespread use in clinical practice is hampered by issues in keeping them up to date, as well as inadequate connectivity with other hospital information systems (HISs), which require manual data input [30].

The study aimed to develop a guidelines-based, multifunctional clinical decision support system for the prevention, diagnosis, and treatment of SSIs.

MATERIALS AND METHODS

Study design

This study is the first experimental part of a pragmatic, non-randomized, historically controlled clinical trial investigating the effect of a CDSS for the prevention, diagnosis, and treatment of SSIs in traumatic and orthopedic surgery in a specialty clinic.

Study setting

In accordance with the *NIH Pragmatic Trials Collaboratory*[1] standards, the first part of the study involved experts from the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics. These experts designed and tested patient safety information system (PSIS) scenarios, collaborated with engineers, were in charge of integration with HISs and system utility refinement, and taught trauma and orthopedic surgeons how to use the system.

The PSIS was implemented in collaboration with trauma and orthopedic surgeons from the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics. They used the scenarios for the prevention, diagnosis, and treatment of SSIs when planning and performing surgical treatment in hospitalized patients.

[1] https://rethinkingclinicaltrials.org/chapters/design/what-is-a-pragmatic-clinical-trial/rcts-pcts-and-qia

The PSIS was designed based on the previous version of a multifunctional automated guideline and clinical audit system, which was first implemented in the Medical Center of the Bank of Russia [31]. Main functions of the PSIS:

- converting recommendations from text regulatory documents and guidelines into automated algorithms;
- configuring algorithms as clinical case datasets, auxiliary algorithms as calculators, and output forms (protocols);
- manual patient data input according to algorithms;
- updating (configuring) the knowledge base of the system;
- automated scenario, calculator, and protocol calculations.

Given that PSISs are continuously developing and must be updated at least once a year, the system must be adaptable and capable of advancing with the knowledge base. For this purpose, a configurable information referral system (CIRS) technology adaptable to various application conditions was used. In contrast to conventional information system, the CIRS enables configuring numerous components, including interfaces, security policy rules, database structure (application environment), and information resource policy rules (business logic) [32].

The PSIS has two user systems: 1) analytical and authoring system (PSIS Manager) intended for subject matter experts to develop scenarios for the prevention, diagnosis, treatment, and auditing of various in-hospital complications (IHCs); 2) medical system for patient data entry and access to guidelines.

One of the key principles for designing the first user system is that clinical experts can create the application environment without the assistance of software developers. This necessitated the development of a user-friendly interface system capable of creating and editing scenarios with an infinite number of questions and responses. It is possible to select the type of each question (single- or multiple-choice questions, single-line or multiline text, number, calculator, date, and time). Questions can be grouped and linked to a response to another question or a set of responses (Fig. 1).

In accordance with the CIRS philosophy, calculators were created to allow clinical experts to develop decision tables, including risk assessment results or computed data (e.g., body weight index, age ranges, etc.). These include the following:

- information calculator that assigns points to specific responses and summarizes them;
- formal calculator that processes a formula using numerical values of responses to selected questions (or calculators);
- time calculator that computes the time from the current day to the specified date or the difference between dates.

A convenient, user-friendly interface with a drop-down hierarchy tree was developed for editing recommendations and creating response-based decision tables (Fig. 2).

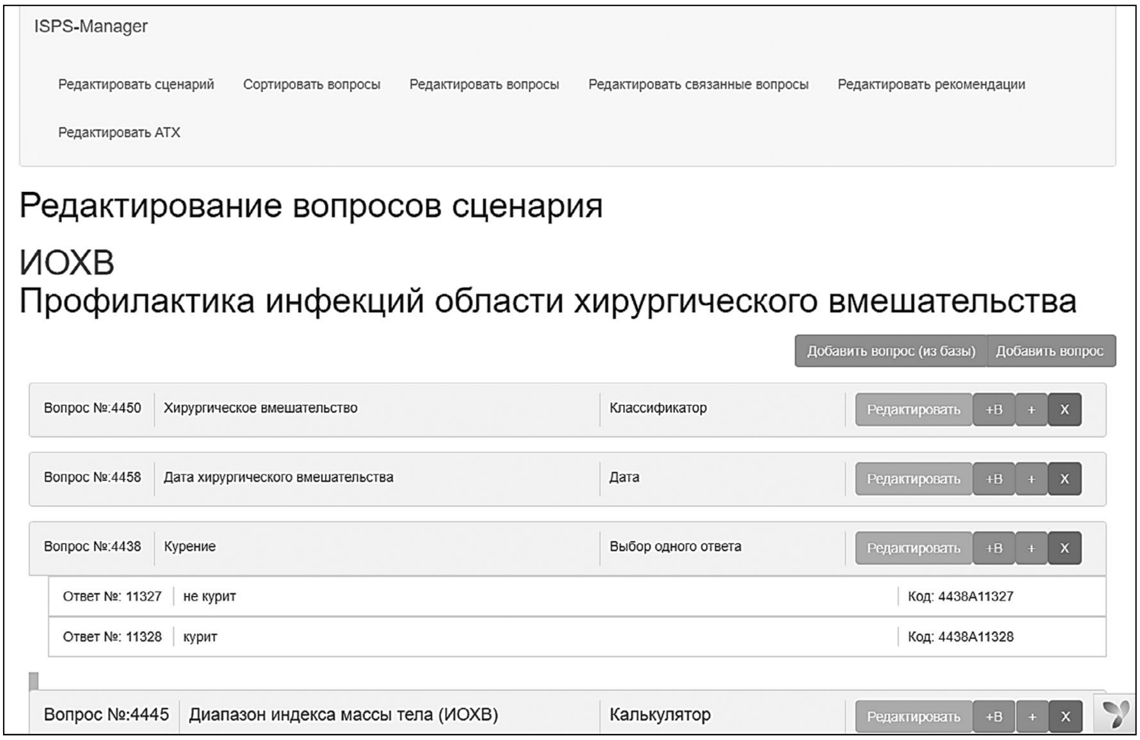

Fig. 1. Interface of the PSIS Manager scenario development system

Recommendations can be grouped in sets. Groups and individual recommendations are assigned ranks that determine their position in a protocol.

Recommendations are text fragments of guidelines. A protocol includes the names of recommendation groups, recommendation wording, indications for which they were included in the protocol, and references to guidelines indicating the evidence level and strength of recommendations, regulatory documents, or prescribing information.

To standardize clinical data, the system includes broad classifiers such as ICD-10, medical service nomenclature, and drug classifications (ATC).

The second user system (Fig. 3), intended for physicians and clinical auditors, has the following functions:

- manual clinical case data input;
- case review and removal at any stage of protocol completion;

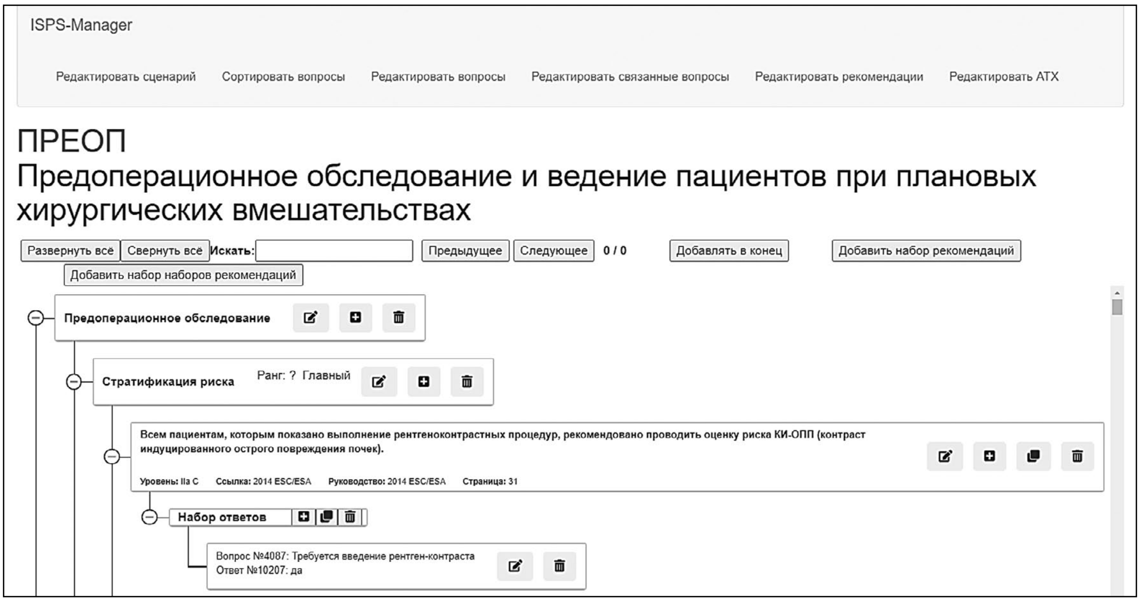

Fig. 2. Recommendation editing interface in the PSIS Manager

Fig. 3. Home page of the intelligent patient safety system for physicians and auditors

- recalculation of recommendations during protocol completion;
- protocol saving and uploading at any stage of protocol completion and protocol signing, after which the entered data cannot be modified;
- access to patient lists and registries according to the user's role;
- creating registry-based incident reports using any set of fields;
- access to recommendation libraries, which allows for data reviewing and uploading.

A so-called navigation scenario ("Create the prevention plan") is provided for new users. This scenario is intended for intelligent decision support on the scope of IHC prevention. As the scenarios are completed, a set of completed prevention protocols is displayed in the top left corner. It is represented by icons with an abbreviated scenario name, color-coded according to the risk of complication to be prevented, where green is low risk, yellow is moderate (intermediate) risk, and red is high or very high risk. Thus, an individual IHC risk profile is formed (Fig. 4).

The PSIS is integrated with a HIS, providing access to a patient's key clinical, demographic, and hospitalization data, as well as enabling export of a prevention or treatment protocol to the patient's medical record in the HIS.

Ethics approval

The study was approved by the local ethics committee.

RESULTS

Scenarios for the prevention of surgical site infections and surgical antimicrobial prophylaxis in traumatic and orthopedic surgery

The PSIS was implemented in the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics in late 2023. The scenario for the diagnosis and treatment of SSIs in traumatic and orthopedic surgery was developed in the summer of 2024.

The scenario for SSI prevention was based on the guidelines of the National Association of Healthcare-Associated Infection Control Professionals [27]. The user can select a surgical intervention according to the medical service nomenclature, indicate the patient's smoking status, perform nutritional risk screening using the NRS-2002 score, and assess nutritional deficiency using the *Mini Nutritional Assessment Short-Form* (MNA-SF) score if the screening result is positive. To select the surgical antimicrobial prophylaxis strategy, the user can assess the surgical wound based on the surgical site microbial contamination using the Centers for Disease Control and Prevention (CDC) classification [33]. Moreover, the user can assess the risk of methicillin-resistant staphylococci carriage and beta-lactam antibiotic tolerance.

The decision tables include 24 recommendations on the antimicrobial prophylaxis strategy, 11 recommendations on the preoperative stage, 20 recommendations on surgical site selection during the perioperative and intraoperative

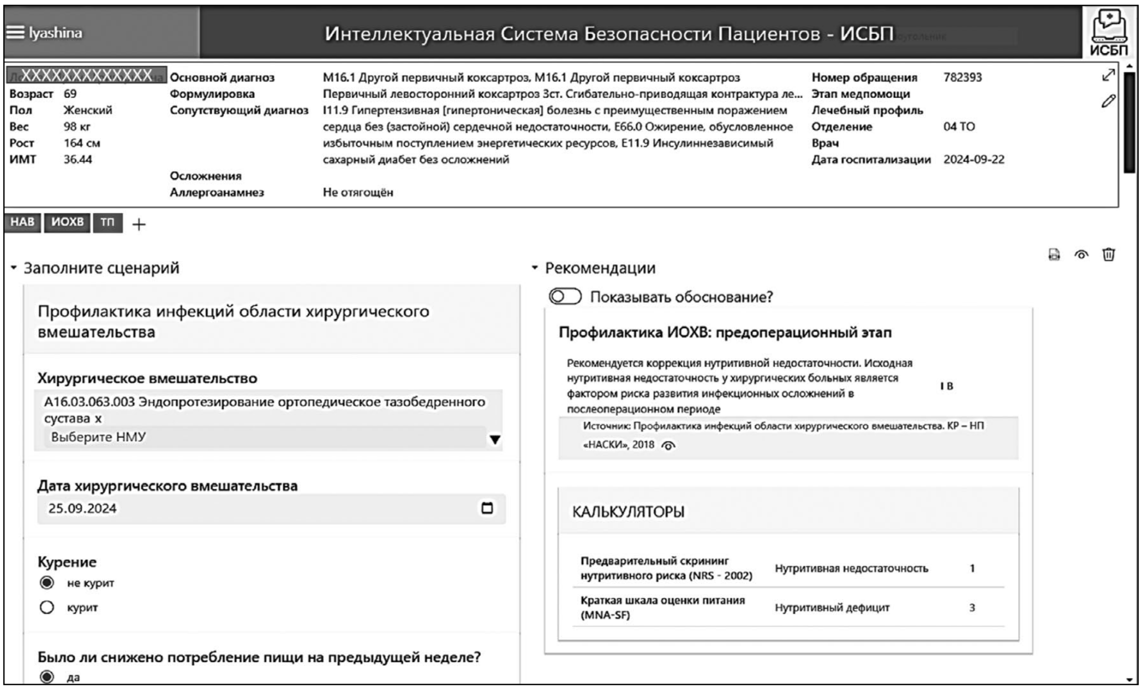

Fig. 4. Completion of a surgical site infection prevention scenario by a physician

stages, 10 recommendations on surgical scrubbing during the perioperative and intraoperative stages, 33 recommendations on SSI prevention in the operating room, and 7 recommendations on the postoperative period.

Scenario-based protocols can be used to support decision-making on patient management strategies during various surgical stages, as well as to control compliance with SSI prevention guidelines.

Scenario for the diagnosis and treatment of surgical site infections

The criteria of the National Association of Healthcare-Associated Infection Control Professionals were used for the diagnosis [27]. They are presented as a calculator with responses to 9 questions associated with the surgery, pathogens (Gram-positive and negative bacteria, *Candida spp.*), laboratory inflammatory markers, and affected tissues and organs. Moreover, the healthcare-associated infection risk is calculated, taking into account the surgical wound classification (clean, clean-contaminated, contaminated, dirty/infected), ASA class, and duration of surgery.

Decision tables for the treatment of SSIs are based on the guidelines of the American Academy of Orthopedic Surgeons (AAOS) [34]. These guidelines were developed with the assistance of 12 experts from various fields: orthopedic surgeons (including pediatric orthopedic surgeons), radiologists, physical therapists, and musculoskeletal infection specialists. To determine the strength of recommendations (Appropriate Use Criteria), another 15 orthopedic surgeons participated in a two-round voting using the Delphi method. Thus, all the recommendations are classified as strong (rating 7–9), conditional (rating 4–6), or rarely used (rating 1–3).

Decisions were made based on the following factors:

- wound infection depth and location (superficial, deep, soft tissues, bones, joints);
- hardware (none, internal fixation, artificial joint, allograft);
- potential risk of complications associated with implant removal (high/low);
- infection classification (acute, chronic);
- antibiotic susceptibility;
- patient's condition (ASA class 1–2 or 3–4).

These six factors and variations in their values provide 264 different clinical scenarios with nine potential solutions:

- systemic antimicrobial therapy alone;
- topical treatment (dressing) with or without antimicrobial therapy;
- surgical wound debridement (superficial and/or deep) with adequate antimicrobial therapy (in cases without hardware);
- surgical wound debridement (superficial and/or deep) with long-term suppressive antimicrobial therapy (in cases of joint replacement);
- surgical wound debridement (superficial and/or deep) with suppressive antimicrobial therapy until the implant is removed (in cases of bone fusion or allografting);
- surgical wound debridement (superficial and/or deep) with implant preservation/partial replacement/partial removal and adequate antimicrobial therapy (in cases of joint replacement, bone fusion, or allografting);

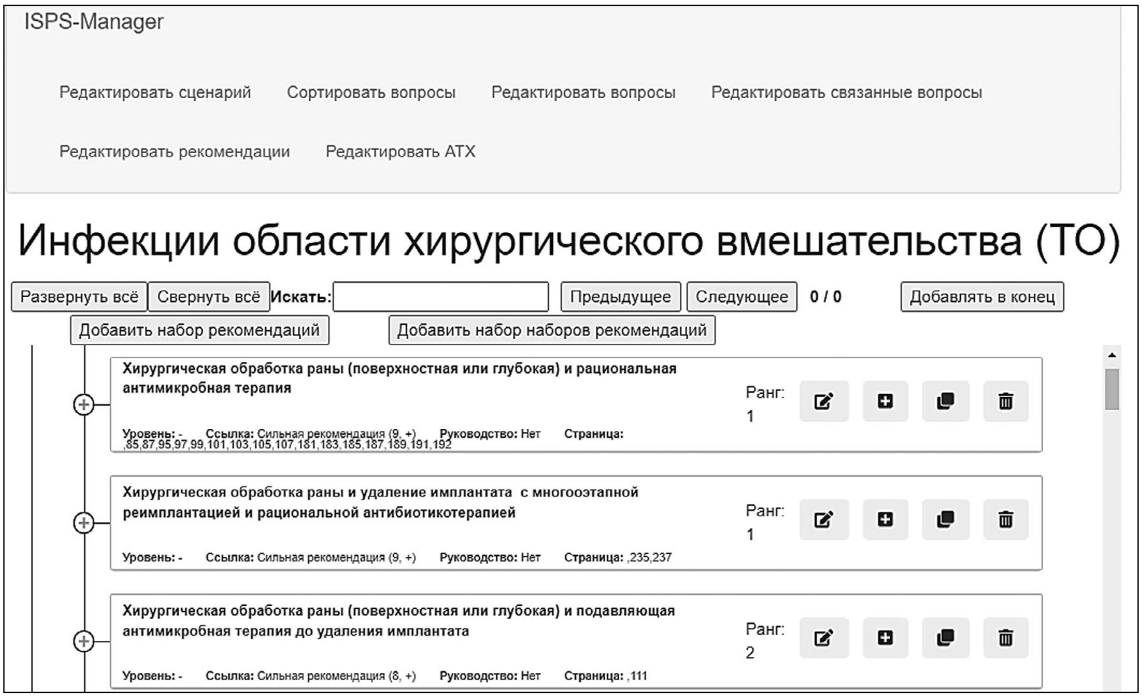

Fig. 5. Recommendations on the treatment of surgical site infections

- surgical wound debridement, implant removal without replacement, and adequate antimicrobial therapy;
- surgical wound debridement, implant removal with immediate replacement, and adequate antimicrobial therapy;
- surgical wound debridement, implant removal with multiple-stage replacement, and adequate antimicrobial therapy.

The strength of each recommendation is determined according to the clinical scenario (1 to 9 points) (total of 1,728 combinations).

The introduction of a decision table into the SSI diagnosis and treatment scenario necessitated additional software development to facilitate the input of datasets.

The scenario is currently being tested (Fig. 5).

DISCUSSION

Medical information technologies are considered a critical factor in improving the quality, efficacy, and accessibility of healthcare. CDSSs have proven to be effective in improving the safety of healthcare; however, there are few publications on their use for SSI prevention and treatment. For example, the deSSIde expert system has been developed using machine learning technologies for predicting the risk of SSIs, with an accuracy of 77.8% [35]. The Dutch experts used a process approach to develop a CDSS that uses HIS-generated data to control various inpatient surgical stages and key process parameters [36].

The distinguishing feature of our approach is a multifunctional PSIS, which combines a conventional CDSS with audit modules, including the ongoing audit of IHC prevention and emerging complications (incident audit). The comparison between the recommended CDSS-based patient management strategy and real-world compliance with guidelines based on audit results allows for conclusions on the preventability of detected complications and efficacy of prevention, as well as determining effective measures against clinical risks. This is especially important for infectious complications, including SSIs, which are preventable in the majority of cases, according to published data.

The introduction of PSISs in real-world practice will provide consistent data collection on healthcare safety and enable business analysis using high-quality, reproducible data owing to integrated classifiers and standardized audit algorithms. Moreover, it will facilitate the use of CDSSs as training tools, implementation of scientific knowledge in real-world practice, and compliance with guidelines. The integration of PSISs and HISs will prevent duplicated data entries on patients and hospitalizations, decreasing physician workload.

CONCLUSION

A multifunctional PSIS intended for clinical decision support in the prevention, diagnosis, and treatment of SSIs in traumatic and orthopedic surgery, prevention audit, and incident analysis of SSI cases has been developed to improve healthcare quality and safety.

The flexible PSIS configuration and the user-friendly interface system enable rapid, cost-effective interdisciplinary automation of guidelines (including patient safety), timely updating of the knowledge base as new guidelines are published, maintenance of the knowledge base without the assistance of software developers, and using audit modules to improve internal healthcare quality and safety control.

Further perspectives on PSIS development in terms of SSI diagnosis and treatment include the use of artificial intelligence technologies to aid in the diagnosis of wound infections and the selection of treatment options.

ADDITIONAL INFO

Autor contribution. All authors confirm that their authorship meets the international ICMJE criteria (all authors have made a significant contribution to the development of the concept, research and preparation of the article, read and approved the final version before publication). A.G. Nazarenko — development of system requirements, scenario expertise, editing of the article; E.B. Kleymenova — requirements and development of scenarios, editing of the article; M.A. Dronov — software support, database design; D.S. Gorbatyuk — scenarios filling out and testing, patient data filling out, literature review, writing of the article; N.M. Kakabadze — scenarios filling out and testing, patient data filling out; A.V. Tsiskarashvili — verification of algorithms, expert evaluation of scenarios, formation of a patients sample, editing of the article; N.P. Gerasimova — technical support of the system, development and testing of calculators; E.S. Yurchenkova — design of integration with EMR, packet data transmission; L.P. Yashina — literature review, collection and analysis of literary sources, writing of the article.

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ДОПОЛНИТЕЛЬНО

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